REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
9 Sep 97

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
Remediation Technologies for Environmental Projects in the United States Military: Part I

5. FUNDING NUMBERS

6. AUTHOR(S)
Scot Tolbert Allen, B.S.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
The University of Texas at Austin

8. PERFORMING ORGANIZATION REPORT NUMBER
97-025

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
THE DEPARTMENT OF THE AIR FORCE
AFIT/CIA
2950 P STREET
WPAFB OH 45433

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

DISTRIBUTION STATEMENT A
Approved for public release
Distribution Unlimited

14. SUBJECT TERMS

15. NUMBER OF PAGES
120

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT

18. SECURITY CLASSIFICATION OF THIS PAGE

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT

DTIC QUALITY INSPECTED 3

Remediation Technologies for Environmental Projects in the United States Military: Part I

by

Scot Tolbert Allen, B.S.

Thesis

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Engineering

The University of Texas at Austin

December, 1997

19970912 ~~045~~ 047

DTIC QUALITY INSPECTED 3

Remediation Technologies for Environmental Projects in the United States Military: Part I

Approved by
Supervising Committee:

James T. O'Connor

G. Edward Gibson, Jr.

Dedication

For Yvonne, thank you for your love and companionship.

Acknowledgments

Many people have contributed to the research and writing of this thesis. I would like to thank my research supervisor, Professor James T. O'Connor for his teaching, his guidance, and his confidence in me. I would also like to thank Professor G. Edward Gibson, Jr., the second reader of my thesis, for his teaching and his support.

To Professors Raymond Loehr, Robert Gilbert, and Kerry A. Kinney, thanks for your help during the development of research topic and scope and of the data collection survey. I would like to thank Chuck Pringle, Donna Shannon, Randy Beyer, and Steven Whatley at Austin Bergstrom Airport for your help in field testing the data survey. Thanks to the many people at the Air Force Center for Environmental Excellence in San Antonio, Texas who supported me in the collection of data for this thesis: Lt Col Richard Ingenloff, Maj Lemoyne Blackshear, Dennis Lundquist, Cesar Silva, Dave McMindes, Denise Etherton, and everyone who shared their time and expertise with me and completed project information surveys.

Thank you to those who have encouraged me to develop my talents and to pursue an advanced degree. Most notably, thanks to my parents Patton and Jacqueline Allen, to my sister Sharon Keller, to Mr. Dick Hodecker, M. Jean-Claude Fontenay and Professor Richard Luthy. Thanks also to the Air Force, particularly Captain Jani McCreary, for affording me the opportunity to earn a masters degree.

Thanks to my family and friends. Allens, Bennetts, and extended family, your support and your love has always been important to me. Finally, thanks to my supportive and loving wife Yvonne Marie.

Thesis submission date: 26 August 1997.

Remediation Technologies for Environmental Projects in the United States Military: Part I

Scot T. Allen, M.S.E.

The University of Texas at Austin, 1997

Supervisor: James T. O'Connor

The purpose of this thesis is to formulate a better understanding of management of environmental remediation projects. Past practices by the U.S. Air Force, other government agencies and private industries around the world have polluted the soil and groundwater at thousands of sites. In only 30 years, the environmental remediation profession has developed hundreds of methods of cleaning-up these sites. The majority of the research conducted previously has dealt with developing innovative technologies to remediate contaminated soil and groundwater. Much less research has examined alternative techniques of project management to improve project technical performance, cost and schedule. Recent findings by the Construction Industry Institute indicate that the great degree of uncertainty in environmental projects warrants different construction management strategies than those used in conventional construction projects. This thesis examines the issues related to selection of remediation technology and contract type.

Table of Contents

Table of Tables

Table of Figures

Chapter 1. Introduction

> *"If we are going to live so intimately with these chemicals-eating and drinking them, taking them into the very marrow of our bones - we had better know something about their nature and their power."*
>
> Rachel Carson

In less than 30 years, environmental remediation has become a major industry in the United States and around the world. Over 300 environmental clean-up technologies have been developed for treatment of contaminated soil and groundwater (Fiedler 1996, Kovalick 1995). Following scientific and societal recognition of the problems posed by pollution, extensive research has been conducted on the effectiveness of various remediation technologies. Much less investigation has been directed toward optimizing cost, schedule and other management aspects of environmental projects. This thesis research is a study into management of environmental remediation projects in the United States Air Force. Variables such as technology selection and contract type will be examined in relation to indicators like cost and schedule performance for a wide range of site clean-up projects.

1.1. Purpose of this Research

The primary objective of this research was to formulate a better understanding of the management of environmental site remediation projects. When this two-part

research study is completed, the combined work will provide a look at technology selection and project management factors which can serve environmental project managers and future researchers.

1.2. Research Scope

This research thesis is Part I of a two-part study of project management of environmental remediation in the Department of Defense (DOD). Part I includes the following activities:

- research project definition
- literature review
- preparation of data collection instrument
- data collection from U.S. Air Force sources
- design and development of a relational database
- recommendations for analysis

Part II will expand the study by conducting the following activities:

- collection of data from U.S. Navy sources
- further refinement of the relational database
- data analysis and presentation of conclusions

1.3. Structure of this Thesis

This thesis is presented in six chapters. Following this overview, the literature review and background materials are presented in chapter two. Next, the study methodology is discussed in chapter three. The fourth chapter focuses on

development of the relational database. In chapter five, proposals are made concerning data analysis to be conducted in Part II of this research, and in the final chapter, conclusions are drawn concerning the work represented in the thesis.

Chapter 2. Literature Review and Background

Although this thesis was primarily concerned with the management of environmental remediation projects, gaining a broad background in environmental engineering and in relational databases was necessary before the research project could be developed. The topics discussed in this chapter will include an overview of the environmental remediation field, concerns peculiar to environmental projects in the U.S. military, a sampling of currently available site remediation technologies, principles of environmental project risk, DOD remediation technology decision models, relational database design, and research hypotheses.

2.1. Environmental Industry Background

Annual spending on environmental protection and restoration in the United States is expected to reach $185 billion by the year 2000 (Kenkeremath 1996). While spending for environmental issues includes pollution prevention and other measures, cost projections for site remediation alone exceed $1 trillion distributed over the next two decades (Blackburn 1993). Since the enactment of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) in 1980, when Congress established a $1.6 billion "Superfund" for environmental remediation of past contaminated sites, it has been recognized that the costs of cleaning up polluted areas will be several orders of magnitude higher than previous estimates (LaGrega 1994). This realization is causing changes in the environmental industry. Optimization of resources and improved risk assessment

and risk sharing have become important goals (Martin 1995). The focus of the environmental industry is currently transforming from "avoiding loss" toward "creating value" (Dunbar 1996).

2.2. Air Force Environmental Perspective

The previous trend of inattention to environmental issues by the U.S. Air Force and her sister services resulted in significant contamination of soil and groundwater under and around DOD installations. Society now understands some of the problems posed by pollution of this type, and many laws and regulations have been passed requiring clean-up of applicable sites. The military is currently engaged in a major effort to remediate these sites on its installations around the world.

2.2.1. Issues

The Air Force has identified more than 4,500 sites that require environmental investigation and possible remediation (AFCEE 1994). Approximately 2,500 of these sites, roughly 60%, are contaminated with petroleum hydrocarbons from aircraft fuels, gasoline, diesel fuel or heating oil (Spain 1992). These fuel hydrocarbons have reached the soil and/or groundwater as a result of spills, leaking storage tanks, and careless past procedures. Examples of other environmental problems on military bases are contaminated soil and water resulting from inappropriate disposal of chlorinated solvents from maintenance activities, heavy metals from painting or weapons training areas, polychlorinated biphenyls (PCBs)

from electrical transformers, and radioactive materials from nuclear weapons activities. In some cases the contaminated soil and water are located in or downstream from landfills and wastewater treatment systems. A number of these sites threaten community drinking water wells or soils in areas accessible to local residents. Many sites are being investigated and some have already been cleaned up, but there is a great deal of work left to be done.

To ensure that this environmental remediation work proceeds smoothly, the Air Force has established the Center for Environmental Excellence (AFCEE) at Brooks Air Force Base, San Antonio, Texas. This center is involved in the management of all environmental projects throughout the service, as well as directing research to identify and investigate cost-effective technologies.

2.2.2. Challenges

Following the dissolution of the former Soviet Union, U.S. military budgets and manpower have been significantly reduced. One of the key challenges is balancing funding for environmental remediation with the need for continued military readiness. Related to this draw-down of forces is the closure of many military bases and their subsequent transfer to local governments or commercial developers. In most cases, state laws require environmentally contaminated property to be remediated before it is transferred. Such remediation will require the acceleration of environmental clean-up on military facilities at a time that overall DOD funding is declining.

Another challenge to environmental remediation in the military arises from our form of government in which individual states retain authority over many issues. The Federal Environmental Protection Agency (EPA) has granted primacy to many states, giving state decision makers the freedom to set their own regulations within certain EPA guidelines (LaGrega 1994). Consequently, the military services must treat similar environmental problems differently depending on the local requirements of each state.

2.3. Management of Environmental Remediation Projects

The Construction Industry Institute (CII) published a research summary in 1995 entitled "Environmental Remediation." This document is unusual in the environmental profession because it focuses on management factors as the key to success in environmental remediation, rather than on technological advances. The CII reached two conclusions:

1. Remediation projects differ fundamentally from conventional construction projects because of uncertainties in site characterization, clean-up technology performance and regulations.
2. It is the effective management of these factors, rather than technological advances, that can result in the largest cost savings in the near term.

In other words, the CII concluded that the need to manage the additional uncertainty and risk, unique remediation technologies, and government regulations distinguishes the management of environmental projects from typical construction projects (CII 1995).

2.3.1. Eight Step Environmental Remediation Process

The CII proposes an eight step model of the environmental remediation process as shown in Figure 2.3.1 (CII 1995).

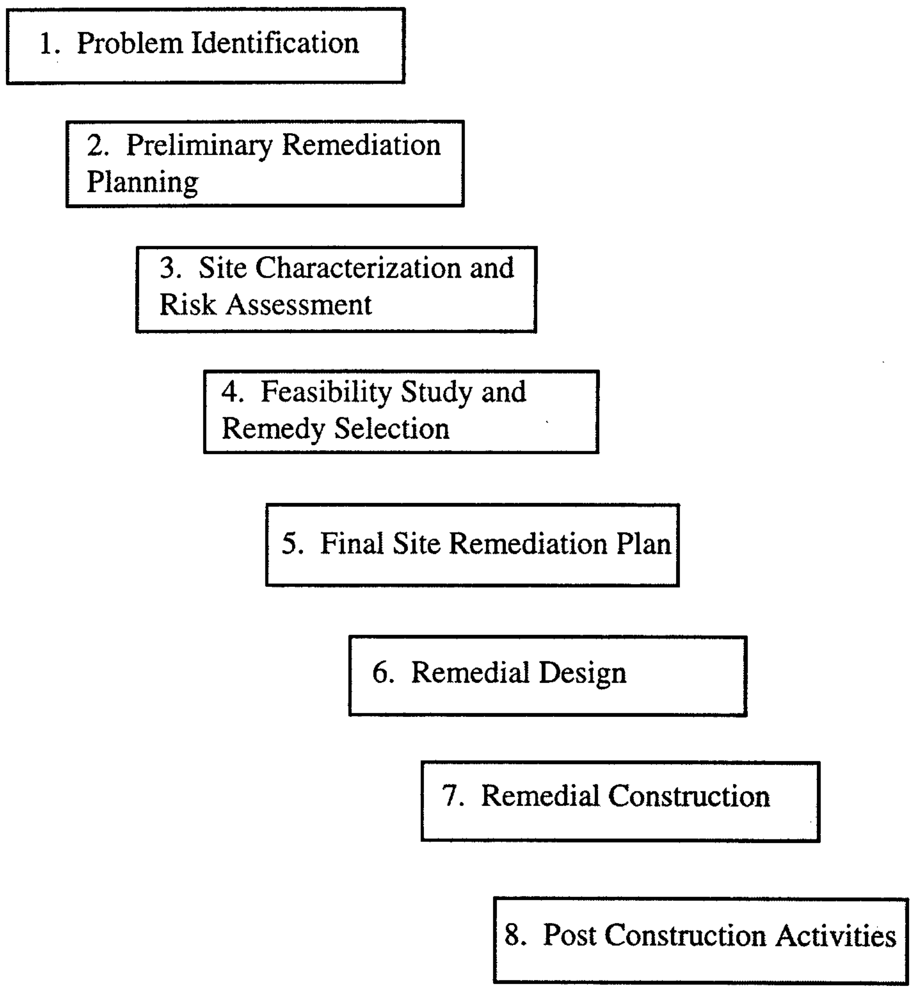

Figure 2.3.1. Eight Step Environmental Remediation Process

The first step is identifying problem sites. This step stresses the importance of immediate response and early evaluation for potential contamination. Nationally, over 30,000 suspected CERCLA sites have been identified.

The second phase, preliminary remediation planning, involves examining general site conditions and expected levels of contamination. At this point the planners must consider current and future site uses as they relate to potential public exposure to the contaminants. A preliminary plan is then developed which outlines major project objectives and limitations as well as possible treatment technologies.

The third step, site characterization and risk assessment, involves collecting data and estimating risk posed by the site. In the United States, over 1200 sites have been placed on the National Priorities List, a list of the Superfund sites requiring action as soon as possible. Site characterization includes identifying the contaminants present, and identifying their concentration, toxicity, and chemical and physical properties. Soil characteristics must be determined, including permeability, particle size distribution, density, and homogeneity. The characteristics of the groundwater must also be examined. These characteristics include depth to water table, extent of contamination, flow direction and velocity. To assess the risk posed by the site, planners must assess current and future site uses. Exposure pathways through soil and air and proximity to surface streams and other sources of drinking water should also be taken into consideration (U.S. Army Corps of Engineers [USACE] 1995). The targeted clean-up level must be established through generic standards or risk assessment, taking into consideration

the priorities of stakeholders such as government officials and local residents (Bell 1996).

Candidate treatment technologies are evaluated in the fourth step of CII's environmental remediation process: feasibility analysis and remedy selection. A project manager must consider many factors to make a sound decision concerning the remediation technology for a particular situation. Some of these decision factors include stakeholder involvement, legal liabilities, and a high degree of uncertainty in site conditions, risk assessment, cost, schedule, and performance projections. The selected remedy must be capable of removing contamination to meet regulatory guidelines, but it also must be cost effective. Additionally, the time required for remediation with the chosen technology must be acceptable to key stakeholders.

Step five of the remediation process is development of the final site remediation plan. This step involves review and finalization of the preliminary plans made during step two. Involvement of stakeholders, including the potentially responsible parties who contaminated the site and will be liable to pay for the remediation efforts, owners, contractors, the government, and the general public must be involved in this phase. Once decisions are made and contracts are written in the next step, it becomes increasingly difficult to alter the project approach.

The sixth step, the remedial design process, includes design of the remediation facility and decisions about how the project will be managed. The decisions made during this step include determining the construction contract type,

arrangements to deal with the potential discovery of additional contamination, contract incentives and penalties, and others.

Step seven, remedial construction process, refers to the actual restoration of the contaminated site. The construction manager and contractor must coordinate closely to properly remediate the site, within the anticipated budget and schedule.

The eighth and final step, post remedial construction activities, involves system operations and maintenance, monitoring, and final closure of the clean-up activities (CII 1995).

2.3.2 Research Recommendations for Improved Management of Environmental Projects

As mentioned previously, two main aspects of environmental remediation project management that differ from conventional construction management are the technology selection decision and the way that risk is managed in the project. Because over 300 different remediation technologies have been developed for environmental clean-up, familiarity with the various technologies and selection of innovative methods is not an easy task. Innovative technologies should be used where they are applicable and would save money and/or time (Dunbar 1996).

In the construction industry, risk is assigned through legal contracts between owners and contractors. The most common type of construction contract, lump sum (also called firm, fixed price) assigns almost all project risk to the contractor. The cost reimbursable contract type assigns the majority of project risk to the

owner. Less common contractual arrangements such as quantity unit cost, guaranteed maximum cost, and time and materials provide means of sharing risk between owners and contractors. The increased uncertainty in environmental projects makes the contract type selection more difficult. According to the Construction Industry Institute, "the unusual features of contaminated site remediation projects suggest that non-traditional or innovative management and contracting strategies may be beneficial." CII research indicates that contracts which share risk yield better results with less cost overruns (CII 1995). In other research, Tim Bosetti concluded that an environmental project requires "better risk analysis" and a "sound contracting mechanism, preferably unit price" which is a way to share the increased project risk between the owner and the contractor (Bosetti 1997).

2.4. Site Remediation Technology Profiles

> *"'If seven maids with seven mops, Swept it for half a year,*
>
> *Do you suppose.' the Walrus said, 'That they could get it clear?'*
> *'I doubt it' said the Carpenter, and shed a bitter tear."*
>
> Lewis Carroll

This section will provide a profile of some of the main remediation technologies currently being used by the U.S. military. Treatment technologies may be categorized into several major approaches including physical, chemical, biological, thermal, and solidification/stabilization (Zuberi 1992). The technologies are also classified by where the treatment takes place: *ex situ* or *in situ*. *Ex situ*

methods require soil excavation or pumping groundwater to the surface prior to treatment. *In situ* methods treat soil and groundwater in place. *Ex situ* treatments can generally be completed more rapidly than *in situ* remediation. For *ex situ* clean-up, there is less uncertainty and more control of treatment parameters. *In situ* remediation is much less expensive and requires less site access and disturbance than *ex situ* solutions. Primarily due to the cost factor, more emphasis is currently being placed on development and use of *in situ* remediation technologies.

Many remediation technologies have been developed to treat contaminated soil and groundwater. The Environmental Protection Agency (EPA) has supported research on these technologies through the Superfund Innovative Technology Evaluation (SITE) program and the Technical Support Project (Scalf 1992). Information on nearly 350 technologies is now available through the EPA's Hazardous Waste Clean-Up Information Web Site on the Vendor Information Systems for Innovative Treatment Technologies (VISITT) database. This database can be downloaded for no charge from within the "Supply and Demand" section of EPA's web site, http://clu-in.com (EPA 1997). The following sections will outline several of these remediation methods

2.4.1. Soil Vapor Extraction

Soil vapor extraction (SVE) is a system designed to remove volatile organic compounds (VOCs), including halogenated organics from soil. This technology is suitable for removal of contamination from the unsaturated soil between the ground level and the water table, known as the vadose soil zone. The SVE system

functions by first extracting contaminated vapors from the soil pores, and then removing contaminants from the off-gases and water, see Figure 2.4.1. Two of the concerns in an SVE system are the presence of soil characteristics which might prevent the even flow of soil gases (leaving pockets of contamination), and the potential short circuiting of the air extraction system. In short circuiting, air flows from the ground surface directly to the extraction wells, bypassing the zone of contamination. Because SVE is an *in situ* treatment method, it is generally less expensive than methods requiring excavation of soil prior to treatment. SVE is not generally recommended if the contaminants have migrated to the groundwater (USACE 1995). However, air sparging (addressed in the next section) or the dual phase vacuum extraction (DVE) method may be used to treat contaminated groundwater and contaminated soil in the vadose zone. DVE uses a high vacuum to draw both soil gas and groundwater from the same extraction well (O'Melia 1996, Lindhult 1996). The unit costs associated with a full scale SVE system range from \$10 to \$40 per cubic yard (DOD 1994).

2.4.2. Air Sparging

Air sparging, also known as *in situ* volatilization, is a system which injects air into a contaminated aquifer. The injected air removes contaminants from groundwater and soil by volatilization. The air is then captured by a vapor extraction system, where contaminants are removed from the off-gases. This system is similar to soil vapor extraction, but air sparging is applied to groundwater while SVE is applied to the vadose zone of unsaturated soil. Air sparging is effective for removal of volatile organic compounds and petroleum hydrocarbons

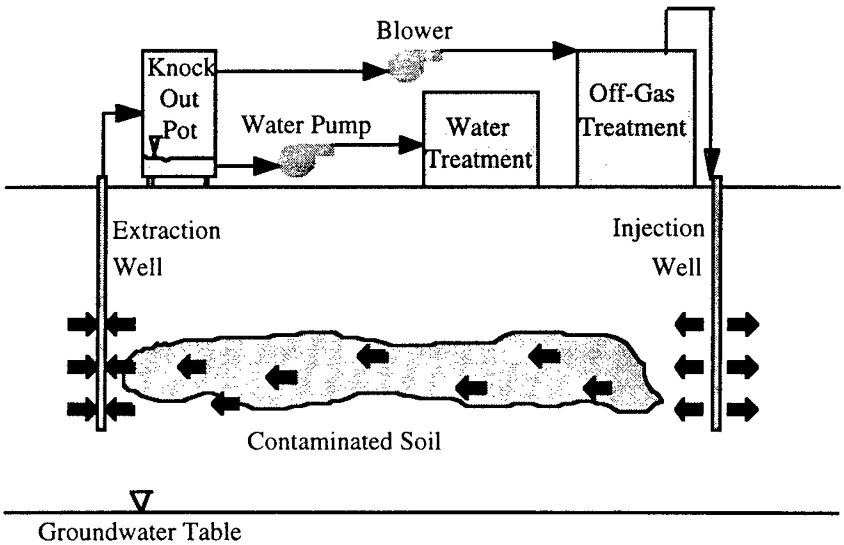

Figure 2.4.1. Typical Soil Vapor Extraction System (USACE 1995)

from water. Some of the limitations are the depth of the contaminants, which must be shallow enough to permit efficient injection and extraction of gases, and soil permeability which must be adequate and fairly uniform. Figure 2.4.2 shows a typical air sparging system. The approximate cost for this technology is $150,000 to $350,000 per acre remediated (DOD 1994).

2.4.3. Biodegradation

This technology relies on the biological processes of degradation by indigenous or inoculated bacteria of contaminants in soil or groundwater. Biodegradation of organic compounds is an extension of the process used in wastewater treatment. Where sufficient oxygen is present (aerobic conditions),

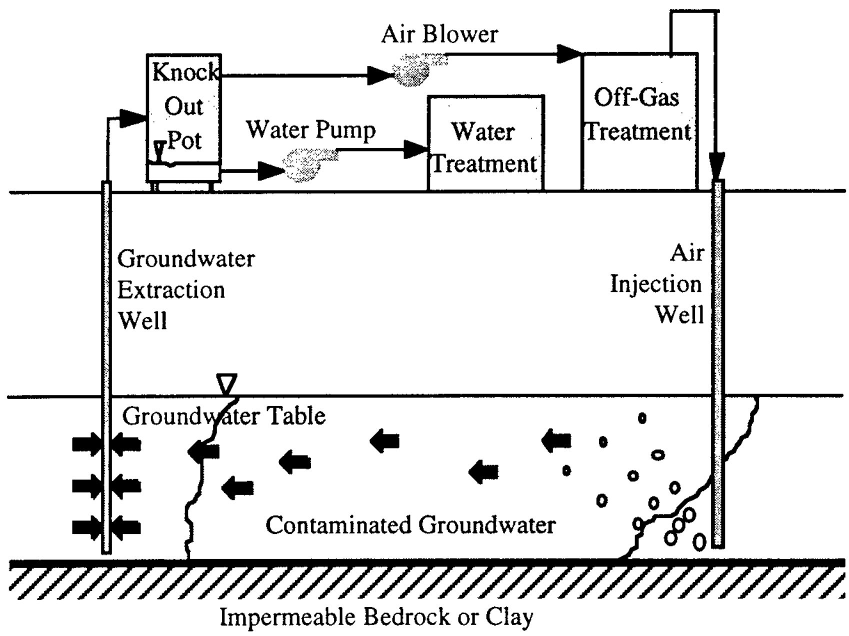

Figure 2.4.2. Typical Air Sparging System (DOD 1994)

organic contaminants will eventually degrade to carbon dioxide and water. Under anaerobic conditions, however, contaminants will be degraded to methane, hydrogen and carbon dioxide. The biodegradation system provides water saturated with dissolved oxygen and nutrients to the subsurface, either by spray irrigation for shallow contamination or by injection wells for deeper contamination. Acclimated microorganisms and other oxidants are occasionally provided in biodegradation systems to accelerate the degradation process. See Figure 2.4.3 for a diagram of this technology.

This technology is suitable for sites contaminated by petroleum hydrocarbons, organic solvents, pesticides and other organic compounds. It is especially suited to

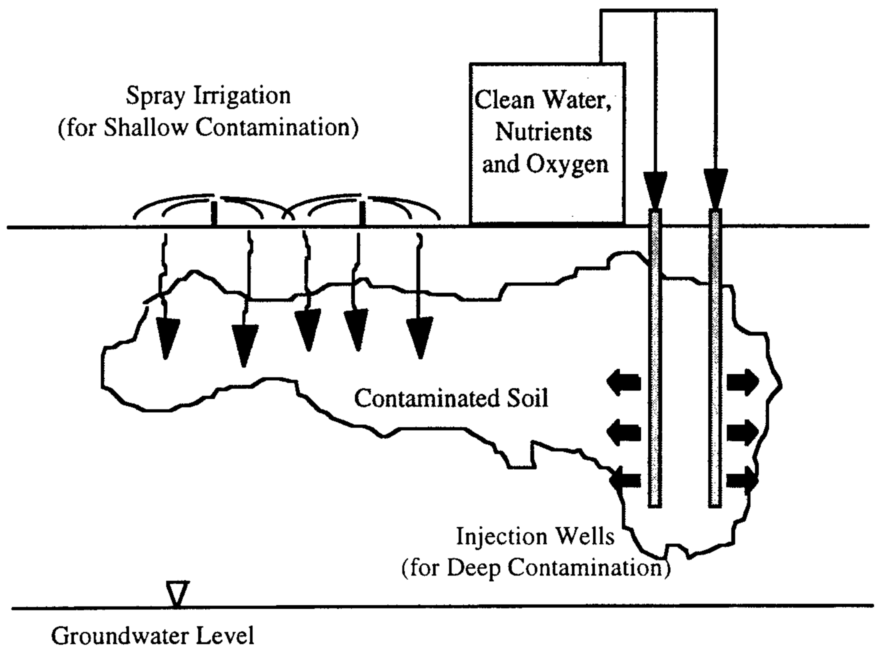

Figure 2.4.3. Typical Biodegradation System (DOD 1994)

clean-up of low level residual contamination. Some of the limitations of this technology are that it requires adequate soil permeability, and biodegradation becomes very slow at low temperatures. Also, in some cases, intermediate products of degradation are more toxic than the original contamination, e.g. trichloroethene degrades to the more persistent and more toxic vinyl chloride. Typical cost range for *in situ* biodegradation is $20 to $80 per cubic yard (DOD 1994).

2.4.4. Bioventing

Bioventing is a method which enhances the intrinsic biological degradation of soil contaminants by providing air or another oxidizing agent to soil bacteria in the zone of contamination (see Figure 2.4.4). Depending on soil conditions, bioventing can be effective for remediation of petroleum hydrocarbons in the vadose zone. Among the many chemical compounds present in fuel contaminated soil, the presence of benzene, toluene, ethene, and xylene (BTEX) are commonly used to indicate the degree of contamination. Bioventing is quite inexpensive, because it operates *in situ* and involves lower air flow (therefore less energy) than an SVE system. Extensive Air Force research at 145 sites nationwide determined the high

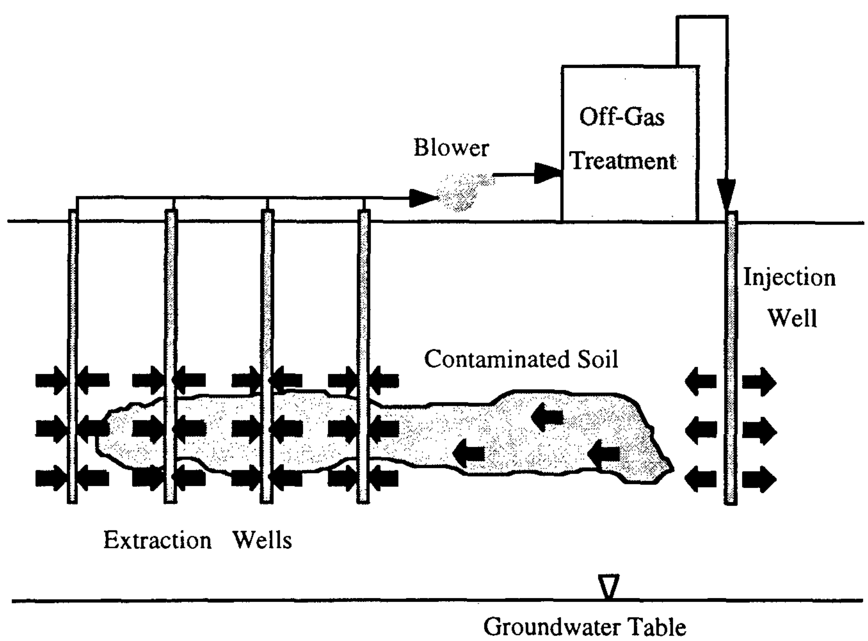

Figure 2.4.4. Typical Bioventing System (USACE 1995)

effectiveness of this method, removing approximately 97% of BTEX during the first year of operation (AFCEE 1996). Bioventing typically costs $10 to $50 per cubic yard of soil treated (DOD 1994).

2.4.5. Chemical Reduction/Oxidation

When the chemical reduction/oxidation (redox) technology is selected, contaminated soil is excavated and then treated chemically to remove contaminants. This technology uses redox reactions to convert environmental contaminants to less hazardous or less mobile compounds. In these chemical reactions, electrons are transferred from one compound to another. One compound is reduced (gains electrons) and the other is oxidized (loses electrons). Ozone, hydrogen peroxide, and chlorine are common oxidizing agents. This technology is an extension of a widely used system for disinfection of drinking water and wastewater. In environmental remediation chemical redox is most applicable to removal of inorganic compounds.

This system is used to treat contaminated soil and groundwater *ex situ*. Two limitations of this technology are that incomplete oxidation may occur, and it is not economical to use this approach to treat highly concentrated contaminants. The estimated cost for treatment ranges from $150 to $500 per cubic yard (DOD 1994).

2.4.6. Composting

Composting of soils is an *ex situ* technology which uses a controlled biological process to degrade contamination. This approach, sometimes called land farming, is applicable to soils and lagoon sediments which are contaminated with organic compounds, such as explosives. It requires the excavation of soil and mixing with organic amendments such as animal or vegetable wastes or wood chips. This mixture increases the soil porosity and provides nutrients for the microorganisms. The soil is then formed into long piles or windrows, which are turned periodically by commercially available farming equipment. For optimal composting efficiency, moisture content, pH, oxygenation and temperature must be monitored.

One of the major limitations of composting is the potential for air pollution. During the excavation and during composting, volatile organic compounds may be released into the atmosphere. Composting is not recommended if volatile compounds are present in the soil. Additionally, precautions must be taken to prevent contaminants from leaching into the soil under the composting area, a large area is required for the composting operation following excavation, and the presence of inorganics (such as heavy metals or high concentrations of organic pollutants) may inhibit biological activity. The estimated cost of land farming is $190 per cubic yard of soil remediated.

2.4.7. Low Permeability Soil Cap

Another treatment alternative is the low permeability soil cap. This solution involves placing a relatively impermeable cap over contaminated soil in the unsaturated zone (see Figure 2.4.7). The goal of the cap is to eliminate surface exposure pathways and to reduce the hydrologic pressure which might leach the contaminants into the groundwater. This remediation method is appropriate for sites contaminated with dense non-aqueous phase liquids (DNAPLs), metals, or semi-volatile organic compounds. If the contamination has already reached the water table, capping is not sufficient. The costs of soil capping are higher than SVE but less than excavation and off-site disposal. A soil cap is frequently used to prevent leachate through abandoned landfills from contaminating groundwater.

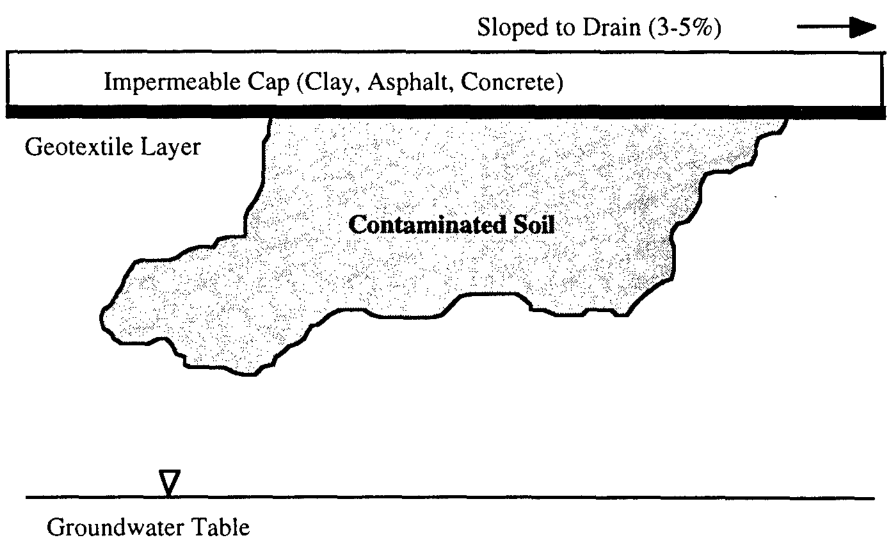

Figure 2.4.7. Typical Low Permeability Soil Cap (USACE 1995)

2.4.8. Passive Treatment Wall

A relatively new technology, permeable passive treatment walls, uses permeable walls placed into a trench in the path of a contaminated groundwater plume to chemically transform contaminants to inert or less toxic substances (see Figure 2.4.8). This remediation method is suitable to remediate groundwater which is contaminated with halogenated organic compounds. For example, treatment walls containing zero-valent iron can reduce chlorinated solvents to chlorides and hydrocarbons. In this process, the iron in the treatment wall is oxidized. Two advantages of passive treatment walls are that they require no energy to operate after installation, and there are no aboveground structures.

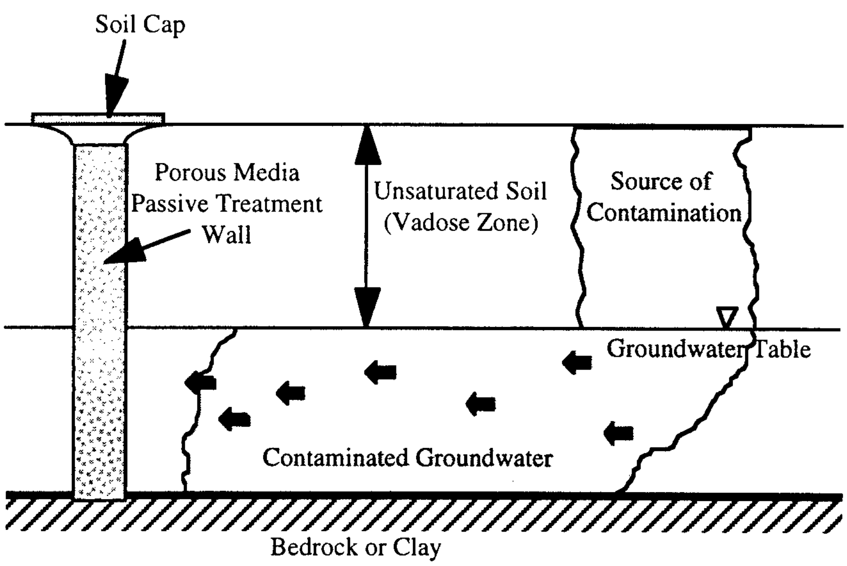

Figure 2.4.8. Typical Passive Treatment Wall (DOD 1994)

Concerns for this system include the difficulty of maintaining a suitable soil pH and the potential need to replace the treatment wall when it loses its reactivity (Fairweather 1996, Wilson 1995). Life cycle costs for passive treatment walls are estimated to be approximately five times less than excavation, roughly $25 to $40 per cubic yard (DOD 1994).

2.4.9. Groundwater Pump and Treat for Containment

The groundwater pump and treat alternative also remediates contaminated groundwater. This remedy is suitable for dissolved phase contaminated groundwater plumes. The pump and treat approach uses air stripping to transfer contamination from groundwater to air, then removes the contamination from the off-gases and polishes the water using activated carbon (Figure 2.4.9). The pump and treat method can remove volatile organic compounds, semi-volatile organics, or dissolved petroleum hydrocarbons from groundwater.

The greatest limitation of the pump and treat remedy is that it is only effective for containment of the contaminated groundwater plume. Frequently, a large volume of contaminated groundwater is present at remediation sites and often there is free product in the aquifer above or below the groundwater. The pump and treat remedy can only be used to keep the pollution from spreading, but is ineffective at removing all contamination from the soil matrix. Another limitation is that metals and certain combinations of contaminants can foul the air stripping and activated carbon systems. Finally, off-gases may require treatment to prevent harmful air

emissions. This technology costs approximately $10 to $30 per 1,000 gallons treated (DOD 1994).

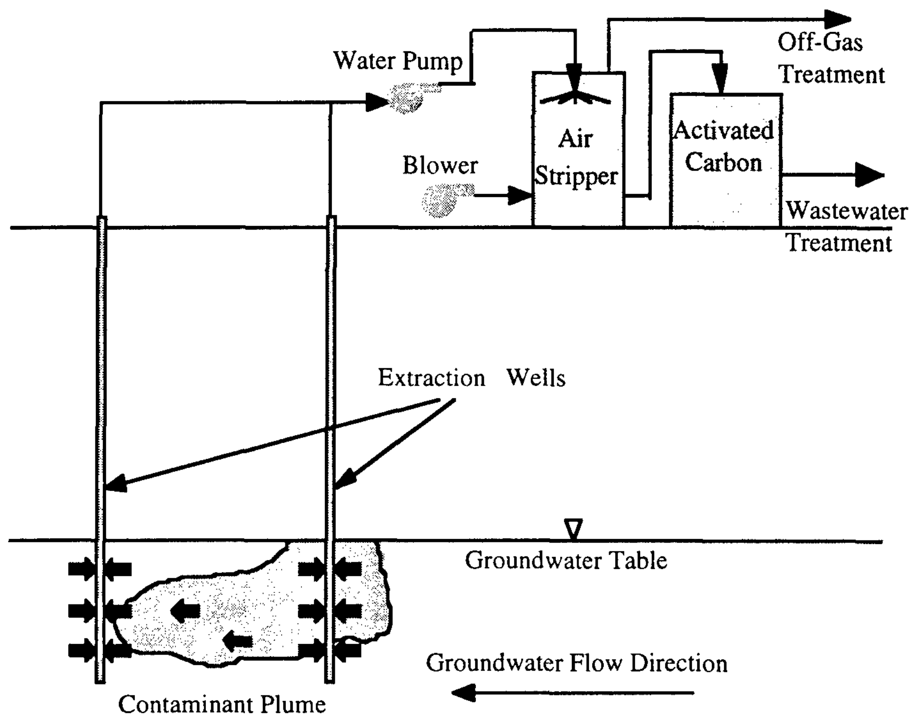

Figure 2.4.9. Typical Groundwater Pump and Treat System (USACE 1995)

2.4.10. Excavation and Land Disposal

In some situations, excavation and land disposal in a designated landfill may be the best alternative. For example, excavation and removal of soils may be best when the project schedule is a driving factor or when another construction project is planned in the near future for the same site. Excavation and off-site disposal may

be used for any type of contaminated soil. However, while removal of the problem soils improves the contaminated site, it does not treat the contaminants.

As in the composting alternative, air emissions are a potential problem with this method. Therefore, excavation is not recommended for soils containing volatile organic compounds. Excavated soil must be placed in legally permitted disposal facilities. The distance to such a facility may be great and will of course affect the cost of transportation. In addition to the travel distance, transportation routes must be carefully considered. Populated areas may oppose shipment of contaminated soil through their communities. Another concern for the excavation alternative is the limitation of commercially available excavation equipment. The depth of contamination must not be greater than the capability of this equipment. The cost of excavation and land disposal ranges from $120 to $200 per cubic yard, or approximately $270 to $460 per ton (DOD 1994).

2.4.11. Excavation and Incineration

In this remediation alternative soils are excavated as in the section above and transported to an incinerator, which is frequently located off-site. Commercial incinerators are typically rotary kilns, with an air pollution control system. Organic wastes are heated to temperatures of 870 to 1200°, at which they are volatilized and combusted. This technology is most effective for treatment of halogenated solvents, fuels, pesticides and other organic compounds.

In addition to the potential for air emissions from excavation and transportation, air pollution from the off-gases of the incinerator are a limitation of this technology. Another concern with incinerator systems is the combustion by-product or ash, which may contain heavy metals or be corrosive, and must be placed in an appropriate disposal facility. The cost of incineration is generally between $90 and $500 per cubic yard (DOD 1994).

2.4.12. Innovative Technologies

The technologies profiled above are only a small subset of the available treatment technologies. This section will briefly address a few of the other technologies available or being developed.

In the previous section we discussed the *in situ* bioventing and biodegradation systems, in which the action of intrinsic soil microbes is enhanced by providing oxygen. Other biological systems are available which remove contaminated soil or water for *ex situ* treatment. These *ex situ* methods, similar to conventional wastewater treatment with high levels of solids, could be appropriate if the soil geochemistry and hydrogeologic conditions do not permit *in situ* treatment (Abbasi 1996).

As petroleum is the world's leading energy source, contamination of soil with petroleum hydrocarbons is widespread (McConagle 1996, DOD 1994). Thermal desorption is a physical process which uses heat to volatilize water and organic compounds from contaminated soil. Unlike incineration, pollutants are mobilized

rather than destroyed. In this *ex situ* technology, wastes are heated to between 90 and 560 °C. During heating, water and organic vapors are carried by over-pressure or a vacuum to the gas treatment system, typically carbon adsorption. This technology is well suited for removal of petroleum hydrocarbons from soil. One advantage of this thermal desorption over incineration is that the soil retains its ability to support biological activity (Bosetti 1997). The cost of thermal desorption is higher than bioremediation because it requires soil excavation. Volatilization of VOCs to the atmosphere during excavation and treatment of soils is also a concern.

Solidification is another relatively new technique for preventing migration of contaminants off site. Cement or fly ash additives are mixed into the soil to retain moisture, solidify the soil, and reduce its permeability. This technology may be applied *ex situ*, by excavating soil and treating it, or *in situ*, by mixing the reagent directly into the soil. This system is effective for inorganics and semi-volatile organics. It is ineffective for containment of volatile organic compounds. The utility of the solidification method is inversely proportional to the depth of the contaminants in the soil (Donnelly 1996, DOD 1994).

A discussion of treatment technologies would not be complete without including natural attenuation. When the level of contamination is below the mandated clean-up standards, or when natural microbiological degradation of organic compounds will remove the contaminants, the best solution may be no action at all.

2.5. Environmental Project Risk Analysis

"If you drink much from a bottle marked 'poison,'
it is almost certain to disagree with you sooner or later."

Lewis Carroll

There are two basic types of risk in environmental remediation projects. The first type, generally called project risk, involves the uncertainty inherent in any construction project as well as the additional risk related to constructing a system in an unknown sub-surface environment. The second type, environmental risk generally refers to the hazard posed by the contaminated site to public health or the environment. This section will discuss the types of uncertainty present in an environmental project, and the impact of these uncertainties on project risk and environmental risk.

2.5.1. Uncertainty and the Value of Information

Uncertainty is an important element throughout the environmental remediation process. Contamination is rarely uniform across a given site, yet it is impractical to evaluate every square meter of soil at all possible depths. Frequently there are more than 100 different chemical compounds present at a contaminated site. The scientific understanding of the health effects of most of these chemicals is quite limited, and is even more uncertain when the compounds are present in combination with one another. Soil and groundwater characteristics are generally complex. Often, clay and sand layers are interspersed throughout a contaminated site

(LaGrega 1994). Future site use is often difficult to predict and requires good judgment from project managers. Unfortunately for planners and cost estimators, the uniqueness of each project and rapidly changing regulations make it difficult to use historical data to reduce the uncertainty associated with environmental remediation projects (Wendel 1995).

Gathering information to reduce uncertainty is expensive. Through decision analysis, it is possible to estimate the value returned by perfect (or improved) information (Clemen 1994, Dakins 1995). The project manager must compare the expected value of better information and compare that to the cost of acquiring that information. In the case of site characterization, the project manager must take representative samples and interpolate these results to the rest of the site. If the project manager fails to accomplish an adequate analysis of the value of improved information, an unreasonable portion of project funds might be spent on "studying" the problem. Money saved by optimizing the site characterization cost can be used for other remediation projects and pollution prevention activities.

2.5.2. Project Risk

Construction is an inherently risky industry. Because each project is unique, there are uncertainties in site conditions, weather, labor and materials costs, delivery schedules, equipment and technology performance. Construction problems are complex and conditions are continually changing (Lifson 1982). In a traditional firm, fixed-price contract, the contractor assumes most of the risk, and seeks to safely construct a quality project on schedule and within budget. In environmental

projects, the variables mentioned above are compounded by additional "uncertainties in site characterization, clean-up technology performance, and regulations" (CII 1995). These factors are causing contractors and owners to find new ways to share risk and control costs (Martin 1995). As the volume of work and the degree of risk increase, risk management modeling becomes increasingly important. Models to assist in risk estimation and selection of appropriate mitigation techniques are emerging (Koch 1993).

Contracts may be viewed as means for assigning risk. As was mentioned above, traditional firm-fixed price contracts assign nearly all risk to the contractor. Cost reimbursable contracts, on the other hand, assign virtually all risk to the owner. Because there is such extensive uncertainty inherent in environmental remediation projects, risk sharing contractual arrangements are often the best alternative (CII 1995, Bosetti 1997).

2.5.3. Environmental Regulations and Risk

> *"We can lick gravity, but sometimes the paperwork is overwhelming."*
>
> Wernher von Braun

Prior to understanding the methods used for risk assessment, it is first necessary to review the legal environment in which remediation technology decisions are made. In the United States, there are currently nearly 30 federal environmental laws and over 90,000 U.S. environmental regulations (LaGrega

1994). This volume of government involvement makes it nearly impossible for any person to be aware of all the applicable requirements that pertain to a given site. To remedy this situation, the National Environmental Policy Institute recommends that the United States should reform its environmental management by adopting a unified statute (Raber 1996). To reduce the federal bureaucracy, others recommend a greater role for local and state officials (Shanoff 1996). Currently, however, project managers are constrained by the present cumbersome system.

Due to the limited understanding of the toxicological effects of various chemicals and the great public concern over hazardous waste sites, regulatory clean-up levels have been driven by conservative upper bound limits of risk. Within the complex legal environment, risk assessment procedures have been based on the best scientific data available. Research has established toxic doses for carcinogenic and non-carcinogenic chemical compounds for laboratory animals. Due to the long duration and expense of these experiments, high chemical doses have been used on relatively small animal populations. Factors of safety have been used to calculate dosage levels which may be toxic to humans from this animal research. In an attempt to protect human health, the permissible human exposure level of hazardous chemicals has been established at much lower levels than the dosages which were found to be toxic to animals. In fact, this allowable human dosage is frequently as many as five orders of magnitude less than the toxic level in animals. These orders of magnitude are used to reduce the uncertainty introduced by various factors. Some of these factors include: variation within a population, extrapolation from animals to humans, and extrapolation from short-term studies to chronic exposure. Estimates of uptake of chemicals into the body following exposure by inhalation,

ingestion and dermal contact have been made. Concentrations of chemicals in soil and water as well as estimated dust emission or volatilization are calculated for a given contaminated site. Researchers determine the exposure routes of local residents or other people who might come into physical contact with contaminated soil or air, or drinking water. Finally, the risk posed by a site is calculated by multiplying the hazard by the exposure. A level of risk which would result in one excess cancer risk per million people from a hazardous waste site is often considered acceptable (LaGrega 1994).

Environmental remediation is expensive. However, in terms of the quantity of contaminants removed from soil or groundwater, the cost of remediation is inversely related to the concentration of the contamination. In other words, it is much less costly to remediate highly contaminated soil or groundwater than to remove trace amounts of contaminants. Conversely, the risk to human health and to the environment is directly related to the level of contamination present. Some clean-up standards require the removal of 99.9999% of contaminants present. This requirement results in very expensive clean-up at the sites which are addressed. If federal and state remediation standards were based on the calculated risk to human health and the environment at each site, it might be possible to adequately protect the public and the environment, while leaving more funding available for clean-up of other polluted sites. The relationships between the level of contamination, the incremental cost to remediate a site, and the risk posed to human health and the environment are presented qualitatively in Figure 2.5.3.

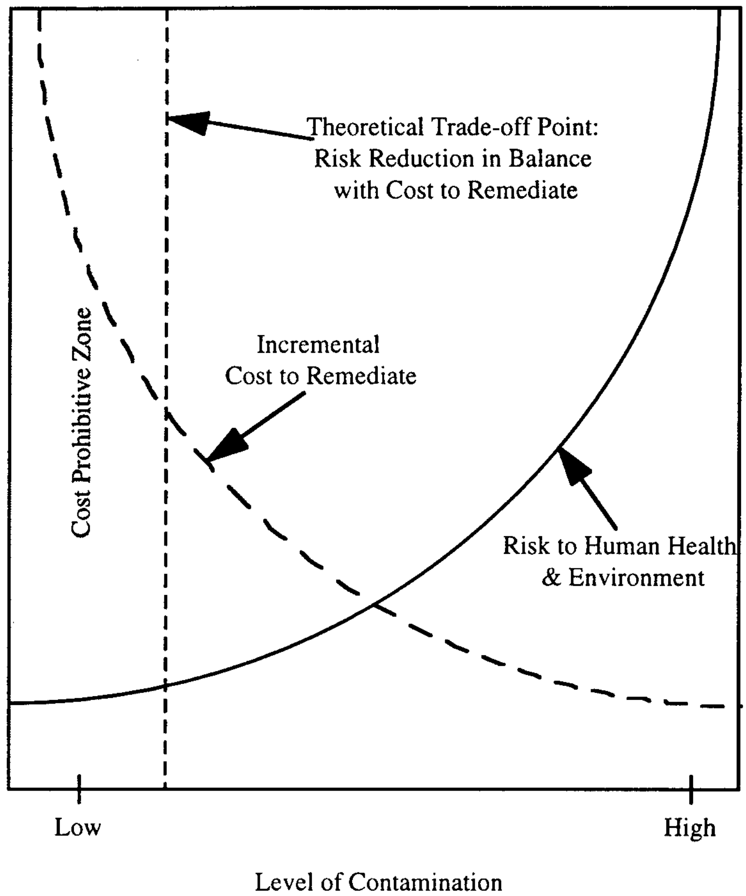

Figure 2.5.3. Environmental Risk versus Incremental Remediation Cost (ESP 1997)

A senior congressional advisor suggests that current methods for assessing environmental risk are inaccurate. Instead of relying on scientific information, policy and value judgments are mixed into the analysis (Kenkeremath 1996). Rather than characterizing the actual site risk, current risk assessment methods establish upper 95% confidence bounds of risk. By focusing on the most contaminated area of the site and remediating the entire site as though it was similarly contaminated, remediation funds which could be used to clean-up

additional sites are wasted (Ginevan 1997, Tusa 1992). To optimize the allocation of remediation resources, research has been directed toward development of risk-based environmental clean-up standards.

The U.S. Air Force has proposed a risk-based approach to remediation of petroleum contaminated sites (Miller 1995, AFCEE 1994). This approach recommends examining the hazard posed by the contaminants, and the potential exposure pathways to determine the risk to the public or to the environment. Petroleum is made up of over 100 different compounds, but "the most soluble, mobile, and toxic of these are benzene, toluene, ethyl benzene, and xylene (BTEX)" (Miller 1995). The levels of these compounds in soil and groundwater and exposure pathways such as ingestion of contaminated water or soil, inhalation of contaminated airborne dust or vapors, and direct dermal contact with the contaminated soil, would be carefully determined. Currently many states require removal of contaminants to an absolute standard, regardless of the potential for exposure. While this may be appropriate for sites near drinking water wells or residential areas where children play, it may be unnecessary for remote or industrial sites which are far from parks, schools, playgrounds, and public water supplies. The Air Force asserts that the public and the environment can be adequately protected by less thorough remediation of petroleum hydrocarbons at some sites than others, and proposes using risk-based standards (AFCEE 1994). Since clean-up of all of the nation's contaminated sites is expected to cost over $1 trillion, using a risk-based approach could potentially save billions of dollars. This approach could also save time. If funding became available because less stringent

remediation was required at the sites that pose less risk to the public, then other contaminated sites could be remediated more rapidly.

Another risk-management model proposes evaluating the value of collecting data to reduce environmental uncertainty by using Monte Carlo simulation (Dakins 1995). This method can help project planners determine the "expected value of sample information (EVSI)" for varying numbers of sampling points, and thus can predict the optimal number of sampling points. This model was tested with data from PCB contamination in New Bedford Harbor, Massachussetts.

2.6. Review of Remediation Technology Decision Models

Because there are so many remediation technologies, several organizations have developed decision methods to assist in technology selection. For example, M. J. Rudin, et al., has built a method for evaluating remediation alternatives in the nuclear industry. This rating system offers a formal procedure to score candidate technologies based on performance data and regulatory and technical requirements (Rudin 1993). Three Department of Defense models for site remediation technology selection are reviewed below.

2.6.1. DOD Treatment Technologies Screening Matrix

The Remediation Technologies Screening Matrix and Reference Guide provides a screening matrix for 55 different remediation technologies (see Table

2.6.1). These technologies have been evaluated based on the following factors: their development status and commercial availability, the residuals generated, the contaminants treated, reliability and maintainability, schedule and cost. Of the three guides reviewed, this one provides the most information to remediation project managers. This guide is particularly helpful to the project manager faced with an unusual site or who wants to find an appropriate innovative technology (DOD 1994).

2.6.2. Air Force Center for Environmental Excellence Remediation Matrix

The Air Force Center for Environmental Excellence (AFCEE) has developed a decision making tool entitled the Remediation Matrix-Hierarchy of Preferred Alternatives (see Figure 2.6.2). This matrix provides a rank ordering of remediation alternatives for a given contaminant and zone of contamination (i.e. dissolved fuel in groundwater). AFCEE has analyzed project data and published this guide to assist project managers in technology selection (AFCEE 1994).

This remediation matrix provides a prioritized list of technologies to consider in the decision process. The matrix is biased toward bioventing, which AFCEE feels is the most cost effective way to treat petroleum hydrocarbon contamination of soil. Under a peer review system now in place in the Air Force, remediation managers who elect not to use AFCEE's recommended solution for a particular contamination scenario must specifically justify the use of another technology.

NOTE: Specific site and contaminant characteristics may limit the applicability and effectiveness of any of the technologies and treatments listed below. This matrix is optimistic in nature and should always be used in conjunction with the *referenced text sections*, which contain additional information that can be useful in identifying potentially applicable technologies.

	Development Status	Availability	Residuals Produced	Treatment Train (excludes off-gas treatment)	Contaminants Treated: VOCs	SVOCs	Fuels	Inorganic	Explosives	System Reliability/ Maintainability	Cleanup Time	Overall Cost	O&M or Capital Intensive
SOIL, SEDIMENT, AND SLUDGE													
3.1 In Situ Biological Treatment													
4.1 Biodegradation	Full	■	None	No	■	■	■	△	■	△	△	●	O&M
4.2 Bioventing	Full	■	None	No	■	■	■	△	I	■	●	■	Neither
4.3 White Rot Fungus	Pilot	△	None	No	△	△	△	△	■	△	△	●	O&M
3.2 In Situ Physical/Chemical Treatment													
4.4 Pneumatic Fracturing (enhancement)	Pilot	△	None	Yes	●	●	●	●	●	■	NA	■	Neither
4.5 Soil Flushing	Pilot	■	Liquid	No	■	●	●	■	△	●	△	I	O&M
4.6 Soil Vapor Extraction (In Situ)	Full	■	Liquid	No	■	●	■	△	△	■	●	■	O&M
4.7 Solidification/Stabilization	Full	■	Solid	No	△	●	△	■	△	■	■	■	CAP
3.3 In Situ Thermal Treatment													
4.8 Thermally Enhanced SVE	Full	●	Liquid	No	●	■	●	△	△	●	■	●	Both
4.9 Vitrification	Pilot	△	Liquid	No	●	●	●	■	△	△	■	△	Both
3.4 Ex Situ Biological Treatment (assuming excavation)													
4.10 Composting	Full	■	None	No	■	●	■	△	■	■	●	■	Neither
4.11 Controlled Solid Phase Bio. Treatment	Full	■	None	No	■	●	■	△	■	■	●	■	Neither
4.12 Landfarming	Full	■	None	No	■	●	■	△	●	■	△	■	Neither
4.13 Slurry Phase Bio. Treatment	Full	●	None	No	■	●	■	△	■	●	●	●	Both
3.5 Ex Situ Physical/Chemical Treatment (assuming excavation)													
4.14 Chemical Reduction/Oxidation	Full	■	Solid	Yes	●	●	●	■	△	■	■	●	Neither
4.15 Dehalogenation (BCD)	Full	△	Vapor	No	●	■	△	△	△	I	I	I	I
4.16 Dehalogenation (Glycolate)	Full	●	Liquid	No	●	■	△	△	△	△	△	△	Both
4.17 Soil Washing	Full	●	Solid, Liquid	Yes	●	■	■	■	■	●	■	●	Both
4.18 Soil Vapor Extraction (Ex Situ)	Full	■	Liquid	No	■	●	●	△	△	■	●	■	Neither
4.19 Solidification/Stabilization	Full	■	Solid	No	△	●	△	■	△	■	■	■	CAP
4.20 Solvent Extraction (chemical extraction)	Full	●	Liquid	Yes	●	■	●	△	■	●	△	△	Both
3.6 Ex Situ Thermal Treatment (assuming excavation)													
4.21 High Temperature Thermal Desorption	Full	■	Liquid	Yes	●	■	●	△	△	●	■	●	Both
4.22 Hot Gas Decontamination	Pilot	●	None	No	△	△	△	△	■	■	■	■	Both
4.23 Incineration	Full	■	Liquid,Solid	No	●	■	■	△	■	●	■	△	Both
4.24 Low Temperature Thermal Desorption	Full	■	Liquid	Yes	■	●	■	△	■	●	■	■	Both
4.25 Open Burn/Open Detonation	Full	■	Solid	No	△	△	△	△	■	■	■	■	Both
4.26 Pyrolysis	Full	△	Liquid,Solid	No	●	■	●	△	I	I	■	△	Both
4.27 Vitrification	Full	●	Liquid	No	●	●	●	■	△	●	●	△	Both
3.7 Other Treatment													
4.28 Excavation, Retrieval, and Off-Site Disposal	NA	■	NA	No	●	●	●	●	●	■	■	△	Neither
4.29 Natural Attenuation	NA	■	None	No	■	■	■	△	△	■	△	■	Neither

Table 2.6.1. DOD Technologies Screening Matrix (DOD 1994)

GROUNDWATER, SURFACE WATER, AND LEACHATE														
3.8	**In Situ Biological Treatment**													
4.30	Co-metabolic Treatment	Pilot	△	None	No	■	■	●	△	●	△	●	●	O&M
4.31	Nitrate Enhancement	Pilot	△	None	No	■	■	■	△	●	●	●	■	Neither
4.32	Oxygen Enhancement with Air Sparging	Full	■	None	No	■	■	■	△	●	■	●	■	Neither
4.33	Oxygen Enhancement with H_2O_2	Full	■	None	No	■	■	■	△	●	△	●	●	O&M
3.9	**In Situ Physical/Chemical Treatment**													
4.34	Air Sparging	Full	■	Vapor	Yes	■	△	■	△	△	■	■	■	Neither
4.35	Directional Wells (enhancement)	Full	△	NA	Yes	●	●	●	●	●	●	■	I	Neither
4.36	Dual Phase Extraction	Full	■	Liquid, Vapor	Yes	■	△	■	△	△	●	●	●	O&M
4.37	Free Product Recovery	Full	■	Liquid	No	△	■	■	△	△	●	■	■	Neither
4.38	Hot Water or Steam Flushing/Stripping	Pilot	●	Liquid, Vapor	Yes	●	■	■	△	△	△	■	●	CAP
4.39	Hydrofracturing (enhancement)	Pilot	I	None	Yes	●	●	●	●	●	■	■	●	Neither
4.40	Passive Treatment Walls	Pilot	△	Solid	No	■	■	●	■	■	I	△	I	CAP
4.41	Slurry Walls (containment only)	Full	■	NA	NA	●	●	●	●	●	■	■	■	CAP
4.42	Vacuum Vapor Extraction	Pilot	△	Liquid, Vapor	No	■	●	■	I	△	■	●	●	CAP
3.10	**Ex Situ Biological Treatment (assuming pumping)**													
4.43	Bioreactors	Full	■	Solid	No	■	■	■	△	●	●	NA	■	CAP
3.11	**Ex Situ Physical/Chemical Treatment (assuming pumping)**													
4.44	Air Stripping	Full	■	Liquid, Vapor	No	■	●	●	△	△	■	NA	■	O&M
4.45	Filtration	Full	■	Solid	Yes	△	△	△	■	●	■	■	■	Neither
4.46	Ion Exchange	Full	■	Solid	Yes	△	△	△	■	△	■	●	■	Neither
4.47	Liquid Phase Carbon Adsorption	Full	■	Solid	No	■	■	●	●	■	■	NA	△	O&M
4.48	Precipitation	Full	■	Solid	Yes	△	△	△	■	I	■	●	■	Neither
4.49	UV Oxidation	Full	■	None	No	■	■	■	△	■	△	NA	●	Both
3.12	**Other Treatment**													
4.50	Natural Attenuation	NA	■	None	No	■	■	■	△	△	■	△	■	Neither
3.13	**AIR EMISSIONS/OFF-GAS TREATMENT**													
4.51	Biofiltration	Full	●	None	NA	■	●	■	△	●	△	NA	●	Neither
4.52	High Energy Corona	Pilot	△	None		■	■	■	●	△	△	NA	●	I
4.53	Membrane Separation	Pilot	△	None		■	●	●	△	●	△	NA	●	I
4.54	Oxidation	Full	■	None		■	■	■	△	●	■	NA	■	Neither
4.55	Vapor Phase Carbon Adsorption	Full	■	Solid		■	■	■	●	■	■	NA	■	Neither

Rating Codes (See Table 3-1)

- ■ Better
- ● Average
- △ Worse
- I Inadequate Information
- NA Not Applicable

94P-5181 10/11/94

Table 2.6.1. DOD Technologies Screening Matrix (~~Contin~~ued) (DOD 1994)

AFCEE REMEDIATION MATRIX - HIERARCHY OF PREFERRED ALTERNATIVES

	POL-Vadose Zone (i.e., jet fuel, diesel)	POL-Excavated Soil	Floating Product Deep (>20ft)	Floating Product Shallow (<20ft) Low Permeability	Floating Product Shallow (<20ft) High Permeability	Dissolved Fuel in Ground Water (BTEX)	Chlorinated Solvents in Vadose Zone (i.e., TCE)	Dissolved Chlorinated Solvents in Ground Water	Heavy Metals in Vadose Zone	Heavy Metals in Excavated Soil	POL Vapor Treatment	Chlorinated Solvent Vapor Treatment
Natural Attenuation/Assimilation	1	1	1	1	1	1	1	1	1	1		
Bioventing	2	4					3 co-metabolism					
Soil Vapor Extraction	3	5					2					
Heat Enhanced Vapor Extraction	4						4					
Low Permeability Cover/Cap	5						6		3			
Excavate and/or Haul	6	8					7		4	4		
Composting (no tilling)		2										
Land Farming		3								2		
Low Temp Thermal Desorp		6										
Incineration (High Temp)		7										
Apparent vs Actual Studies			2	2	2							
Passive Extraction Wells			4	5	4							
Hand Bail if Appropriate			3	3	3							
Vacuum Assist Pumping			5	4	5							
Dual Pump System			6									
Air Sparging*						3		3				
Passive Treatment Wall						4		4				
Conventional Pump and Treat						5		5				
Slurry Wall						6		6				
Stabilization							5		2	3		
Permitted Direct Emission											1	1
Flare											2	
Biological Filter											6	4 co-metabolism
Catalytic Incineration											4	2
On-site Regenerated Polymer											5	3
Carbon Adsorption											7	
Internal Combustion Engine											3	
GW Recirculation/Stripping						2		2				5

THIS MATRIX IS AN ATTEMPT TO RANK TECHNOLOGIES/PROCESSES THAT SHOULD BE CONSIDERED FOR USE AT COMMON AIR FORCE SITES. MANAGERS SHOULD USE THIS HIERARCHY FOR SCREENING TECHNOLOGIES/ PROCESSES AND SHOULD BE ABLE TO JUSTIFY WHY A PARTICULAR TECHNOLOGY/PROCESS WAS SELECTED OVER OTHERS WITH LOWER NUMBERS. FOR INSTANCE, IF SOIL VAPOR EXTRACTION (3) IS THE SELECTED TECHNOLOGY/PROCESS FOR POL IN THE VADOSE ZONE, THEN MANAGERS SHOULD BE ABLE TO JUSTIFY WHY NEITHER NATURAL ATTENUATION (1) NOR BIOVENTING (2) WAS SELECTED. THE NATURAL ATTENUATION/ ASSIMILATION SHOULD ALWAYS BE CONSIDERED FIRST AND, IF SELECTED, SHOULD BE BASED ON A SCIENTIFICALLY DEFENSIBLE RISK ASSESSMENT. SELECTION OF THIS TECHNOLOGY/PROCESS SHOULD BE ACCOMPANIED BY FIELD SAMPLING AND MODELLING TO QUANTIFY AND PREDICT NATURAL ATTENUATION RATES. A LONG-TERM MONITORING PROGRAM SHOULD BE IMPLEMENTED TO VERIFY NATURAL ATTENUATION MODEL PREDICTIONS.

* VERY SUSCEPTIBLE TO SUBSURFACE HETEROGENEITIES. APPLICABLE WHERE THE INSTALLATION OF A HIGH DENSITY OF SPARGING (EXTRACTION) POINTS IS ECONOMICALLY FAVORABLE.

Table 2.6.2. AFCEE Remediation Matrix (AFCEE 1994)

2.6.3. U.S. Air Force Presumptive Remedy Engineering Evaluation/ Cost Analysis

The United States Air Force Presumptive Remedy Engineering Evaluation/Cost Analysis (PREECA) is a guide to four Air Force recommended environmental remediation alternatives (USACE 1995). A presumptive remedy is one which is recommended for a range of projects meeting certain common criteria. In this guide, these presumptive technologies are soil vapor extraction, bioventing, impermeable soil capping, and groundwater pump and treat for containment. The applicability of each method is shown in Figure 2.6.3.1. The Air Force Presumptive Remedy guide also provides information on the applicability of the various technologies in tabular format (see Figure 2.6.3.2).

The Presumptive Remedy guidance offers a simple method of selecting an applicable treatment technology for most of the environmental contamination scenarios faced by the Air Force. By limiting its scope to just four technologies, it is easy to understand. Unfortunately, there are situations where these technologies are not applicable, and by considering only four options, it is possible to overlook a better alternative.

The complexity of the environmental remediation field also drives different agencies to emphasize greater cooperation to avoid duplication of effort (Bartell 1993). The above models for site remediation technology selection provide examples of Air Force-wide and DOD-wide strategies for environmental clean-up. The next section turns from technology selection issues to the computational structure used to manage information gathered during the research.

Technology	Remedy Profile Summary
SVE	- Halogenated hydrocarbon contamination in the vadose zone - Average soil gas permeability greater than 1 x 10^{-3} darcies; - Average percent saturation of the vadose zone less than 60%; - Depth to groundwater or contamination greater than 5 feet; - Henry's Law constant of contaminant at 20 degrees Celsius greater than 0.01 (dimensionless); and - Vapor pressure of the majority of the contaminant at 20 degrees Celsius greater than 1.0 millimeters Mercury (mm Hg).
Bioventing	- Fuel, BTEX, or THC hydrocarbon contamination (i.e., non-halogenated hydrocarbon) in the vadose zone; - Soil gas permeability greater than 0.1 darcies; - Initial soil pH between 5 and 9; - Initial soil moisture content between 5 and 25%; - Initial soil total Kjedalh nitrogen content of $\geq$ 20 mg/kg soil; - Initial soil total phosphorus content of $\geq$ 3 mg/kg soil; and - Unsaturated gravels and minor clays and silts, thorougly fractured bedrock.
Capping	- DNAPL, semivolatile, or metal/inorganic contamination in the vadose zone; - Area of capping contamination less than 24 acres (excluding landfills); - Depth of contamination greater than 18 feet below ground surface (BGS) and/or total volume of contaminated soil greater than 1,800 cubic yards for a hazardous waste or greater than 7,500 cubic yards for a non-hazardous waste; - Construction will not impact environmentally sensitive areas; - Existing structures can be removed and future land use can be restricted; - Henry's Law constant of contaminant at 20 degrees Celsius less than 0.01 (dimensionless) (for DNAPL only); - Vapor pressure of contaminant at 20 degrees Celsius less than 1.0 mm Hg (for DNAPL only); - Geology is complex and soils are heterogeneous (for DNAPL only); and - Hydraulic conductivity of subsurface < 10^{-4} cm/sec (DNAPL only).
Pump and Treat for Containment (P&T)	- Organics and/or inorganics in the groundwater; - Source or discharge point of contamination remediated or not active; - Concentration of halogenated VOCs are less than 1 percent of maximum solubility; - Solubility of contaminants is greater than 10 milligrams per liter; - Adsorption coefficient is less than 10,000 liters per kilogram; - Total volume of groundwater contaminant plume is greater than 1,000 gallons and less than 5 billion gallons; - The target plume is contained in porous deposits (i.e. sands, gravels with minimal interlayered silts and clays) or highly fractured or weathered bedrock and/or average hydraulic conductivity is 10^{-4} centimeters per second for the saturated zone; - Natural organic carbon fraction is less than or equal to 0.01; - Natural groundwater velocity is greater than 10^{-7} meters per second and less than 10^{-4} meters per second; - Water level fluctuation is less than 10 feet per year and 3 feet per day; - Surface water provides upgradient recharge and minimal flood potential; and - The target plume is either underlain by an aquitard in an unconfined water table zone or is confined between to aquitards.

Table 2.6.3.1. Presumptive Remedy Profile Summary (USACE 1995)

Remedy Profile No.	Contaminants and Associated Pathway		Presumptive Remedy Profiles			
	Surface and/or Vadose Zone Pathway	Groundwater Pathway	Capping	Soil Vapor Extraction	Bioventing	Pump and Treat for Containment
1	Non-VOCs	None	✓			
2	VOCs	None		✓		
3	TPH/BTEX	None			✓	
4	None	VOCs and/or Non-VOCs				✓
5	TPH/BTEX and Non-VOCs	None	✓		✓	
6	VOCs and Non-VOCs	None	✓	✓		
7	Non-VOCs	Non-VOCs	✓			✓
8	VOCs	VOCs		✓		✓
9	VOCs and Non-VOCs	VOCs and Non-VOCs	✓	✓		✓

Table 2.6.3.2. Applicability of Four Presumptive Remedies (USACE 1995)

2.7. Relational Database Background

A relational database is a powerful tool to facilitate management and analysis of data, and is an ideal structure for storage and management of the data collected during this research project. A database must be well organized for ease and speed of search and retrieval. The model of a relational database was first proposed by E. F. Codd in the 1970s. In a relational database, information is stored in tables which are linked together. Each table is designed to capture information about a particular subject, and is linked to other tables with related information (Daniel 1996).

2.7.1. Database Design Concepts

For ease of management, the tables in a database should not be so large as to make data entry difficult. On the other hand, too many small tables can make the database architecture overly complex. In each table, information is stored in rows, called records, and in columns, called fields. A record is a collection of information about a particular person, project, product, or activity. A field is a category of information that may refer to many projects or activities.

There are three levels in database design: logical, physical, and user level. The logical design is the foundation for the database design and operation. It involves identifying the tables and fields required and designing the relationships between them. The physical design is based on the particular computer hardware and software used to implement the logical design. The user level design provides the user interface with the data and restricts access to certain users, if necessary.

The referential integrity, or relationships, between the tables and fields is provided by a system of keys. Each table has a primary key, such as a project identification number, to ensure that each record has a unique description. Two tables may be linked together by including a foreign key, which is simply the primary key of the first table, in the second table (Daniel 1996). The following example may help to illustrate these concepts. In one table, information may be stored about employees: name, identification number, address, telephone, etc. In a second table, information may be stored information about sales made by the company. Since each employee may make many sales, but each sale is made by only one employee, we may include the employee identification number in the table concerning sales. In the "sales" table, the employee ID number serves as a foreign key to the table containing detailed information about that particular employee.

2.7.2. Microsoft® Access

Microsoft® (MS®) Access is a versatile relational database program which is commercially available and operates on IBM compatible computers. MS® Access allows data which is stored in tables containing records and fields to be viewed and manipulated in a variety of ways. Some of the database features which can improve management of data are forms, queries and reports (Microsoft® 1994).

Forms may be developed for ease of data entry. An MS® Access form can be laid out to resemble a paper form, and data entered in the form will automatically update the related table containing the information. Forms can also be used to edit

and to view data that has been entered. Custom-created forms can allow database users to view the data in whatever arrangement best suits their needs.

Queries are a method for drawing useful information from the larger database, for example one might query a project database to identify all projects which made use of the soil vapor extraction technology, or projects which were completed under budget. Queries are the first step in data analysis, and can use single or multiple search criteria to allow database users to quickly find the fields and records they want to view.

Information from the records and fields of one or more tables can be arranged, as desired, in reports. Reports are generally printed on paper and are ideal for data presentation. This database software is well suited to manage information concerning environmental remediation projects, and an MS® Access relational database will be developed for the data collected in the course of this research.

2.8. Research Hypotheses

In the course of this two-part research study, several hypotheses related to technology selection and project management will be tested:

- Projects in which the guidance of the AFCEE remediation technology selection matrix is followed are more successful than those which do not;
- The great majority (95%) of the technology selection decisions made in military projects are reasonable based on the site characterization;

- Contract types which assign all risk to the contractor or owner are less successful than risk sharing contractual arrangements; and
- One reaches a point of diminishing returns in site characterization and study, beyond which project success does not significantly improve.

It is recommended that these hypotheses be tested formally in Part II of this research effort. Data collected from both the Air Force and the Navy should be analyzed to determine the validity of the hypotheses.

Chapter 3. Study Methodology

The procedure followed in conducting this research is shown in Figure 3.0. This research study entails all of the steps shown in the figure, from project definition to database development, suggestions for data analysis, and writing of the present thesis. Part II of the overall research project will include collection of additional data from U.S. Navy environmental project managers, enhancement of the relational database, and analysis and presentation of all the data collected from the Air Force and the Navy. Future refinement of this research could include the collection of data from the U.S. Army, other government agencies, or the private sector. In this chapter, Part I of the research project will be explained: the process of developing this research thesis.

3.1. Definition of Research Objectives and Scope

Environmental remediation is an important part of the Air Force engineering mission, undertaken to protect public health and the environment. Remediation projects are necessary both for the closing of Air Force bases to be transferred to local authorities and for the safety of personnel on and near operational bases. A significant portion of the Air Force facilities engineering budget is spent on environmental work, and this emphasis is expected to continue into the foreseeable future. For these reasons, and due to the author's personal interest, environmental remediation was selected as the research topic.

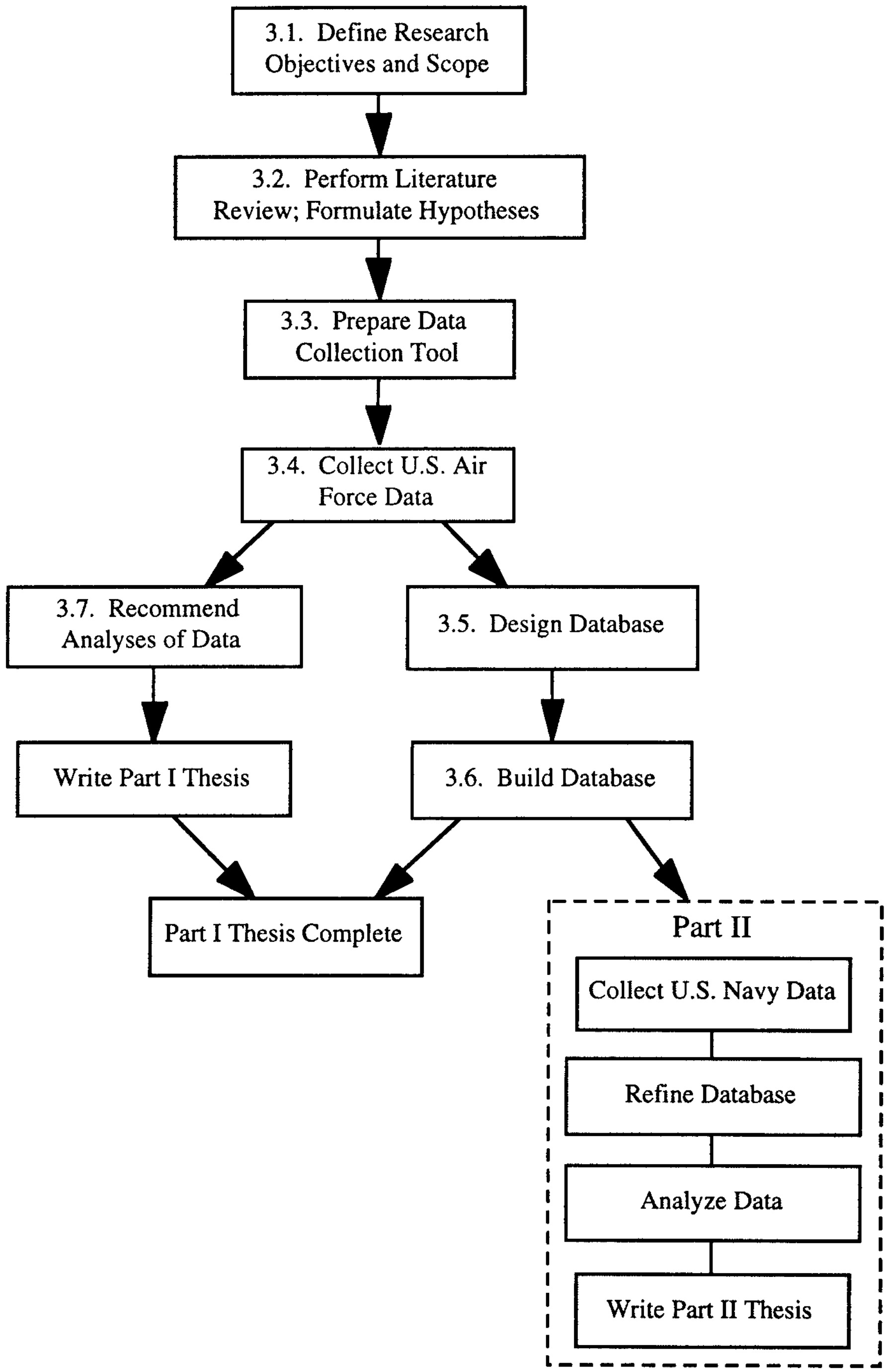

Figure 3.0. Research Plan

The dramatic increase in demand for environmental remediation worldwide has prompted a great deal of research into development of clean-up technologies. Relatively little attention has been given by researchers, however, to the management of these environmental remediation projects. Therefore this research focuses on project management aspects of environmental remediation.

The objectives of this research are to:

- develop a data collection tool for technology selection, contract type, and other project management information
- collect data from project managers
- develop a relational database to provide flexible access to this project information
- recommend analyses of the data

The scope of this research is limited to an examination of technology selection and management of environmental remediation projects in the U.S. Air Force. This research includes the elements outlined in Figure 3.0.

3.2. Literature Review and Formulate Research Hypotheses

With the research objectives and scope in mind, a thorough review of relevant literature was conducted. This review yielded a background understanding of the issues involved in the environmental industry, concerns in military environmental restoration, technology selection and management of environmental projects, and relational database design. This literature review provided the groundwork for

formulation of hypotheses, development of the data collection tool and all the work that followed.

The research hypotheses were based on the concepts developed in the literature review. The hypotheses relate technology selection and other project management concerns to project results.

3.3. Preparation of Data Collection Tool

The data collection tool, or project survey, was created after setting goals and determining the type of information desired. The first goal in project survey development was to design a tool which would collect information concerning the nature of the environmental problem, the technology selected and other elements of the solution, the contract arrangements, and the project results. The next goal was to limit the survey to the most important project information, with a maximum length of two pages. This short length helped to ensure maximum response to the survey. Then, the target audience was selected. Due to the author's professional association with the Air Force, it was decided that the primary audience of the survey would be Air Force environmental project managers.

Next, the types of projects to be surveyed were determined. Ideally, the survey responses would include projects using a wide variety of technologies, with a range of different contract types, and would include projects that were highly successful and others whose results were below original expectations. These ideas were communicated to survey respondents in the cover letter and in personal

conversations with the project managers. Then the number of desired completed project surveys was determined. To acquire a useful number of data points, but remain realistic about survey response, a goal of 20 to 50 completed survey responses was set. Finally, an incentive was designed to encourage survey response. Financial bonuses were beyond the resources of the researcher, so copies of the completed database were offered instead. Each survey respondent was asked if he or she would like an electronic (disk) copy of the relational database.

First, a draft version of the data collection tool was created and examined by the research supervisor. Subsequent iterations of the survey were reviewed by professors in the faculty of the Environmental and Water Resources Engineering and Geotechnical Engineering programs. Next, the data collection tool was field tested by Air Force environmental project managers at Bergstrom Austin Airport. The final version of the survey had been improved by several levels of review. The final data collection tool and cover letter sent to project managers can be found in Appendix A.

3.4. Data Collection from U.S. Air Force Remediation Managers

Since Air Force environmental remediation project managers were identified as the primary data collection audience, it was next necessary to identify Air Force employees and contractors in this line of work. Air Force employees and contractors at Bergstrom Austin Airport provided feedback during survey

development and provided project information once the survey was completed. Project managers at the Air Force Center for Environmental Excellence (AFCEE) at Brooks Air Force Base in San Antonio, Texas also provided extensive project data for the research.

3.5. Design of Relational Database

Designing the relational database on MS® Access involved learning both about database design in general and about the particular software chosen. There are five steps in the design of a relational database (Microsoft® 1994). These are:

1. Determine the purpose of the database.
2. Identify the tables required.
3. Determine the fields needed.
4. Determine the relationships between the tables and fields.
5. Refine the design.

These steps were followed to design a database which is flexible enough to accept additional project data expected to be gathered in Part II of this research project, and powerful enough to allow easy analysis of the data in various ways.

3.6. Database Building

In this process, the tables and fields required by the design were built using MS® Access 97. Primary keys for each table were identified, and the tables were linked together by using foreign keys. Some tables had one-to-one relationships to

other tables, while the rest had one-to-many relationships. Special database building techniques were used to create these relationships.

3.7. Recommended Analyses of Data

After an informal review of the data, and considering the research hypotheses formulated after the literature review, certain analyses of the data collected were recommended. Basically, these suggestions were correlations of project inputs to project outputs. The inputs include such items as type of contamination present, depth to groundwater, geological features, technology selected and contract type. The outputs are mostly the items in the "results" portion of the survey, including cost and schedule performance, and overall project results. From another perspective, technology selection can be considered an output of the site characterization. The technology selection decision can then be analyzed against the contamination profile to evaluate the soundness of the selection.

Chapter 4. Relational Database Development

This chapter explains the decisions made and the process undertaken to design and build the relational database. The first five sections correspond to the five steps in database design introduced in section 3.5. The last two sections deal with customizing forms for data entry and entering the project information in the database.

4.1. Purpose of the Database

The primary objective of the relational database is to effectively manage the data collected using the thesis survey. Supporting this main purpose are several goals. These are to facilitate data entry and analysis, allow future changes as the research project develops, accommodate data from Navy and potentially from Army or private sector sources as well as the Air Force, and provide flexible easy access to data by database users.

4.2. Tables in the Database

The centerpiece of the design, to which all other tables were related, was the table entitled "projects." This table contained information identifying each project uniquely. Five tables were linked directly to "projects." The first of these was the table "survey respondents." This table contained names and contact information for each person who completed one or more project surveys. The second table was the

table “site problems,” which included the information related to the contamination and site characterizations. The remaining three tables were “project solutions,” “contract type and issues,” and “project results.” Each of these were designed to capture the information from the corresponding sections of the data collection tool.

Several sub-tables were also required because a number of the questions had multiple responses. These questions, which instructed the survey participant to check all answers that apply, required separate tables to track their responses. For example, in response to the question “contaminants present (check all that apply),” for some projects the managers checked only one box, but for other projects several boxes were checked. To track this information, it might have been possible to provide several columns in the “site problems” table, but often some of these columns would be left blank. As the Microsoft® Access User’s Guide explains, sometimes there are “fields that are intentionally left blank in many records because they aren’t applicable to those records. This usually means that the fields belong in another table” (Microsoft® 1994). Another problem with adding fields for additional contaminants was that this would complicate data analysis later. The solution was to build a separate table containing a list of the potential contaminants. In the end, this solution will improve data accessibility during analysis, although it was more complex to design. For a complete view of all the tables in the database, see Figure 4.2.

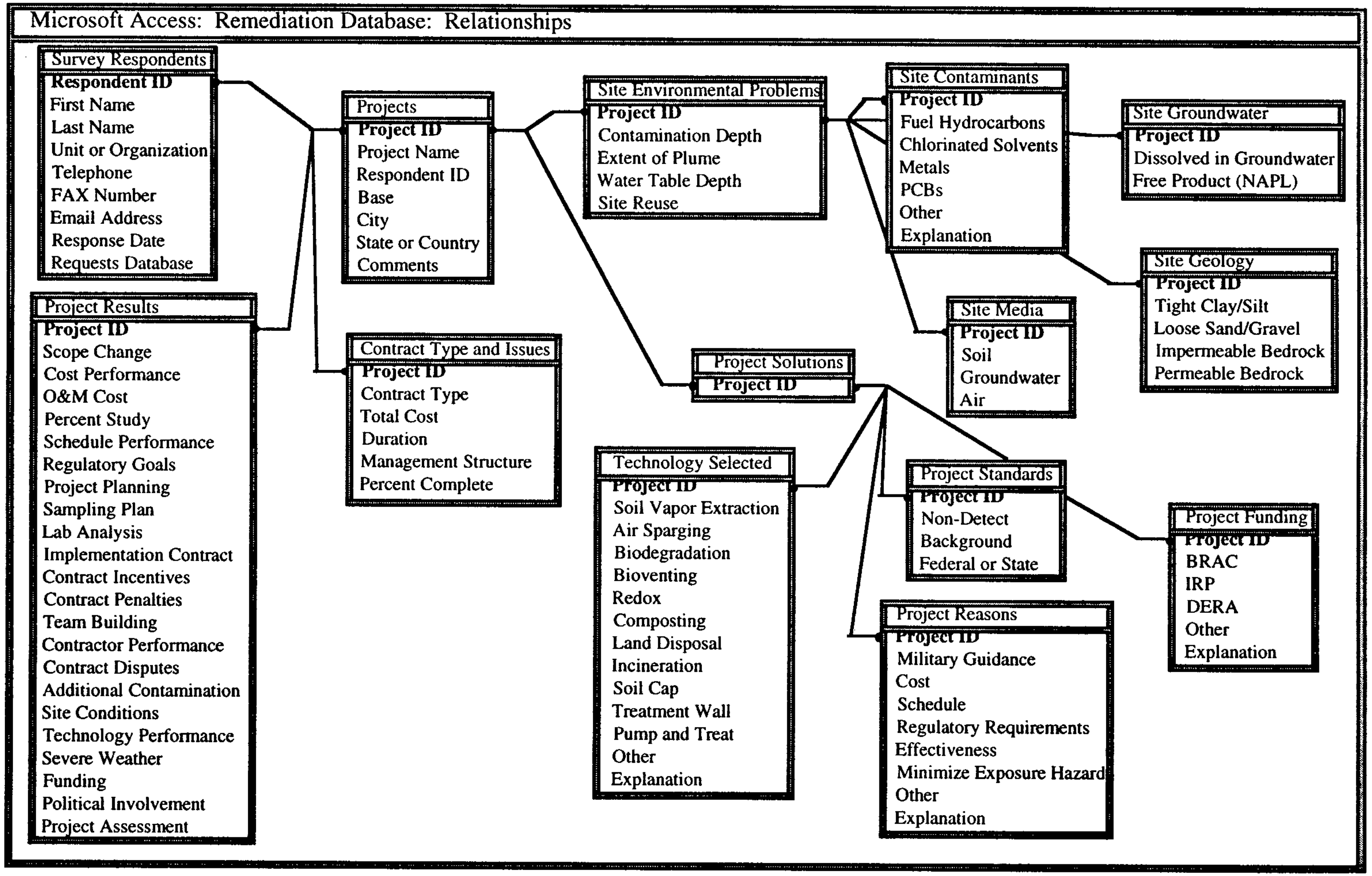

Figure 4.2. Relational Database Structure

4.3. Fields in the Tables

The next step was to determine which fields had to be created in each table. When determining which fields to include in a table, it is also important to identify the primary key field. That field will uniquely identify each record stored in the table, or allow the database to quickly find and bring together information stored in separate tables. All of the fields including the primary key fields (shown in bold print) are identified in Figure 4.2. Rather than repeat the information shown in that figure, this section explains the rationale behind the field selections for a few example tables.

Since the table "Projects" was the basis for the rest of the database, it will be covered first. The fields in this table began with the primary key "Project ID," an automatically assigned number which provided a unique means of identifying that particular project. This primary key provided the link to all other tables in the database. The field "Respondent ID" identified the project manager who provided the information about this project. "Project Name," "Base," "City," and "State or Country" provided additional information about each project. The "Comments" field was a place to collect the information written on the back of the survey form, in response to the question which asks for "other comments on the project."

The next table to examine is "Contract Type and Issues," which stored data concerning the contract used for the remediation project. The primary key field of this table was "Project ID," just like the table "Projects." The other fields all store

information about the contract: "Contract Type," "Total Cost," "Duration," "Design Type," and "Percent Complete."

The last table to examine is "Project Technologies Selected." This table contained a series of "yes or no" questions concerning each of the available technologies, such as soil vapor extraction and composting and passive treatment wall. Check boxes were filled for each technology used in the project in question.

4.4. Relationships Between the Tables

There are three possible relationships between tables in a database: one-to-one, one-to-many, and many-to-many. The first two of these relationships exists in the site remediation projects database. The relationship of the "Survey Respondents" table to the "Projects" table is one-to-many, because while each project is related to only one survey respondent, each participant in the study may be associated with several projects. The relationship of "Contract Type and Issues" and "Projects" is one-to-one. For each project, there is only one set of contract data, and each set of contract data refers to only one project.

4.5. Refinement of the Design

Several alternatives were considered for the relationships between the tables. In an earlier iteration of the design, some tables were related to the "Projects" table by complex many-to-many relationships. This was impractical and the current

design was an appropriate solution. Another problem with the early design is that many tables were linked directly to the "Projects" table. This made it more difficult to understand the structure of the database, and harder to see the similarity to the paper form of the data collection tool. This was corrected during step five, refinement of the design. The final design is the one shown above in Figure 4.2.

4.6. Development of the Forms

Forms are Microsoft® Access objects that facilitate data entry, editing and viewing. Since MS® Access forms can be designed to resemble paper forms, and data entered in forms will automatically update the related tables, forms were used in this database to make the data entry process simpler. Forms were created for each group of tables and these were laid out similarly to the paper data collection tool. For the many multiple choice questions in the survey, check boxes and list boxes were created. These data entry structures provide menus which, in most cases, are similar in appearance to the options presented on the paper form.

4.7. Data Entry

Once the database was properly designed, the tables were created with primary keys and other fields, the relationships between tables were established, and the data entry forms were built, the actual data entry was fairly straightforward. In most instances, data were entered in the same order as it appears on the data collection tool. There were a few exceptions to this pattern. For example, the

comments that the study participants wrote about each project on the back of the survey form were included in the main "Project" table which appears toward the top of the electronic form. Also the question on the back of the form asking whether managers desired a copy of the completed database was included in the "survey respondents" form, which is encountered early in the data entry process.

Chapter 5. Suggested Data Analysis

"It is a capital mistake to theorize before one has data."
[Sherlock Holmes] Sir Arthur Conan Doyle

The scope of this thesis is limited to research project definition, literature review, preparation of the data collection tool, collection of data, and development of the relational database. Additional data collection, analysis, and presentation of the data will be accomplished in Part II of this research study. This chapter offers some preliminary comments on the data collected to date and suggests analytical tests which might be carried out on the final data set. The recommendations in sections 5.2 through 5.6 are analytical tests which might provide insight into management of environmental remediation projects. Once all of the data is collected, it may or may not be practical to conduct all of the analyses proposed here. Additionally, other relationships may be discovered that warrant analysis.

5.1. Comments on Data Collection and the Project Survey

Project data were collected following project definition, literature review, study methodology determination, and survey development phases. The author personally contacted senior and middle managers at the Air Force Center for Environmental Excellence and Bergstrom Austin Airport, and requested their support for the research project. With the assistance of these higher-level managers, the author then distributed project surveys to environmental remediation

project managers. The data collected are included in Appendix B. For confidentiality, the identities of the individual survey participants are not provided in this thesis.

5.1.1. Survey Response Level

Approximately 120 data collection surveys were distributed personally to project managers or their supervisors. As of 1 August 1997, data on 35 projects were returned in person, by mail, and by fax. Thus, the survey response rate was approximately 29%. Since participation in the research was voluntary, and the goal was to collect data on 20 to 50 projects, the survey response was satisfactory. A higher response rate might have been achieved if the higher-level project managers had been persuaded to *require* their workers to complete the survey. However, the project managers who participated in the survey did so willingly and were cooperative and helpful when follow-up questions arose.

Fourteen survey respondents provided data on 35 environmental remediation projects. Feedback from survey respondents indicated that completing each survey took between 10 and 20 minutes. Five respondents returned one survey each, while one project manager completed six surveys. Interestingly, only three of the project managers requested copies of the database. Three of the people who expressed a desire for the database and/or a copy of the report were the supervisors and leaders of the project managers and team chiefs.

5.1.2. Limitations of the Data

It is important to realize the limitations of the data collected. The source of the data was Air Force employees and contractors who acted as project managers and team chiefs for environmental clean-up at closing Air Force bases and at some operational bases. There is an inherent bias in any data that asks for personal judgment, such as "evaluation of overall project results." In the cover letter delivered with the survey and in conversations with respondents the author requested information on a range of projects, including successful and unsuccessful projects. Air Force managers selected the projects about which they would provide information. Thus, these responses are not necessarily a representative sample of all Air Force environmental remediation projects. Also, incomplete responses to some of the surveys will present a challenge in data analysis.

5.1.3. Comments on the Data Collection Tool

The project survey was scrutinized by several professors and was field tested on project managers prior to general data collection. However, certain recommendations were received which could further improve the survey's clarity. First, the words "hazardous waste" in the title of the survey should be removed. Hazardous waste is explicitly defined in regulations of the Environmental Protection Agency. As was pointed out by one survey participant, petroleum hydrocarbons or the unknown contents of abandoned landfills are not defined as hazardous waste. Therefore, the author recommends using the phrase "environmental site remediation" instead of "hazardous waste site remediation" in the title of future

versions of the survey and avoiding the specific mention of hazardous waste, where possible.

There was also a concern about the word "failure" in the "key factors" question on the second page of the survey. Project managers were concerned about the strong connotations of that word. The author recommends that future versions of the data collection tool should ask about the "impact of key factors on project outcome (1-positive, 2-no major impact, 3-negative, 4-N/A)." This would avoid the word "failure," which may be too strong.

The final recommendation is to number the questions on the survey. Particularly in the data analysis phase of the project, it will be important to be able to refer to specific questions on the survey. Question numbers will facilitate discussion of the results and data analysis.

5.2. Correlation of Site Factors to Technology Selection

The first suggested analysis of the data is to examine whether an appropriate remediation technology was selected, given the site contamination and site characterization. This analysis tests the second research hypothesis and prepares for testing the first research hypotheses in section 5.3. The first two hypotheses were:

- Projects in which the guidance of the AFCEE technology selection matrix is followed are more successful than those which do not;

- The great majority (95%) of the technology selection decisions made in military projects are reasonable based on the site characterization.

This analysis is expected to involve evaluating the type of contamination, the media affected (soil, groundwater, air), the site geology, and the site reuse plan. Comparison of the site factors to the AFCEE technology selection matrix, or similar guidance from the Department of the Navy, would determine whether the technologies selected followed the guidance of the matrix. A suggested graphical display of this analysis is shown in Figure 5.2, identifying the number of projects with a particular contamination profile for which each technology alternative was used. This analysis would also determine whether the remediation technology used for each project was an appropriate choice, enabling the researcher to confirm or refute the second research hypothesis.

5.3. Relationship of Technology Selection to Project Results

The next recommended analytical test is to determine whether there is a correlation between the technology or combination of technologies selected and "overall project results" and "technology performance." This would give an indication of the effectiveness of the various technologies. The researcher should keep in mind, however, that many of the answers are the subjective judgment of the survey participants, and that the projects were not selected at random. A graphical representation of the suggested method of analysis is shown in Figures 5.3.1 and 5.3.2. To perform this analysis, the researcher will need to assign scores to the

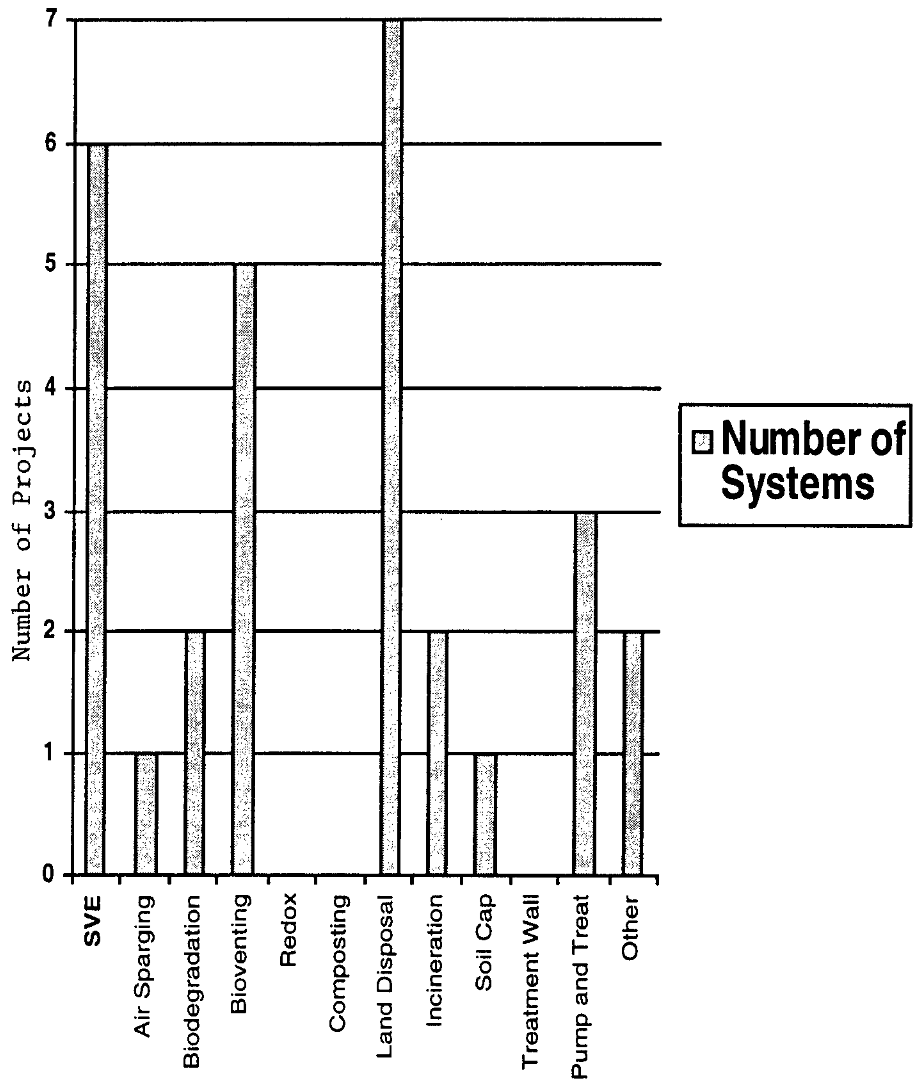

Figure 5.2. Suggested Analysis of Technology Selection for a Given Contamination Profile

possible outcomes. For example, for the question concerning overall project results, the answer "successful" might be assigned a score of 80% or 8 points,

"acceptable" might be assigned a score of 50% or 5 points, and "unacceptable" could be given a value of 20% or 2 points.

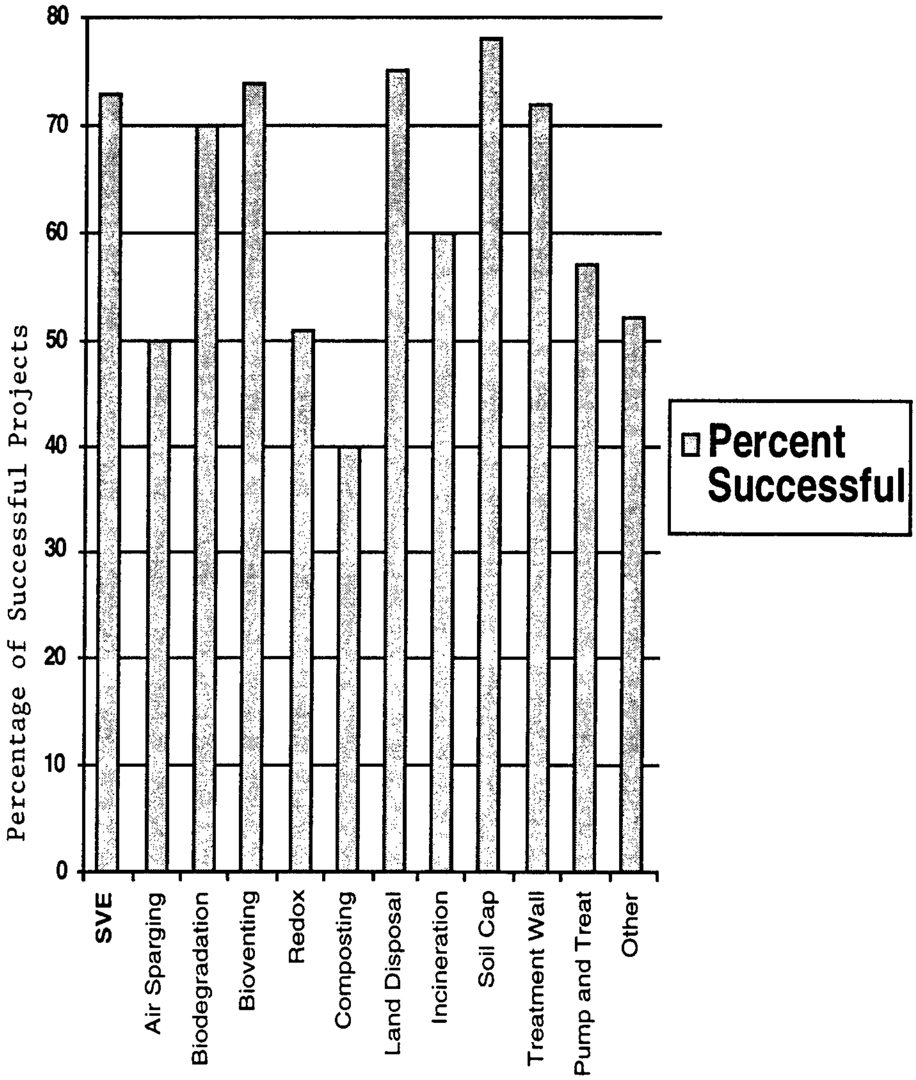

Figure 5.3.1. Suggested Analysis of Technology Selection and Project Results

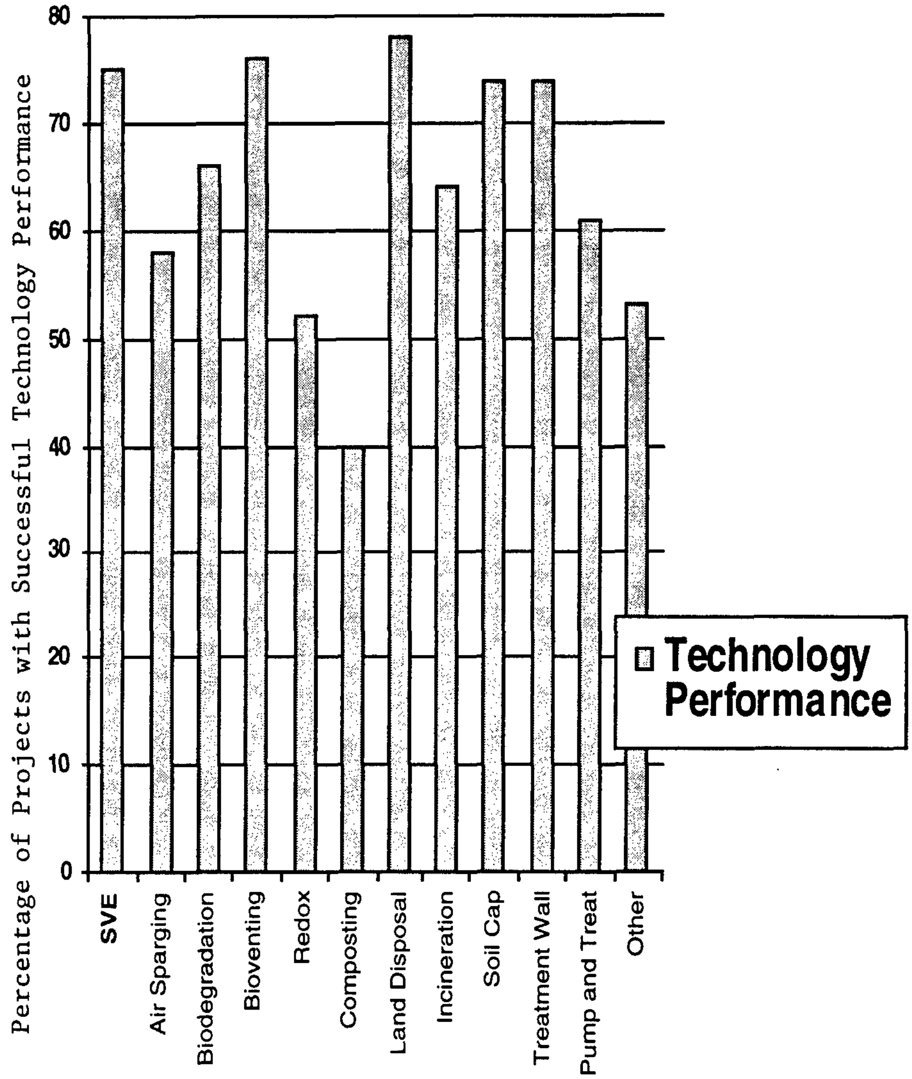

Figure 5.3.2. Suggested Analysis of Technology Selection and Technology Performance

The next suggested analysis relating technology selection to project results is to evaluate the impact of technology selection on cost and schedule performance (see Figures 5.3.3 and 5.3.4). In these analyses, the researcher may further study the relationship between remediation technology selection and project results.

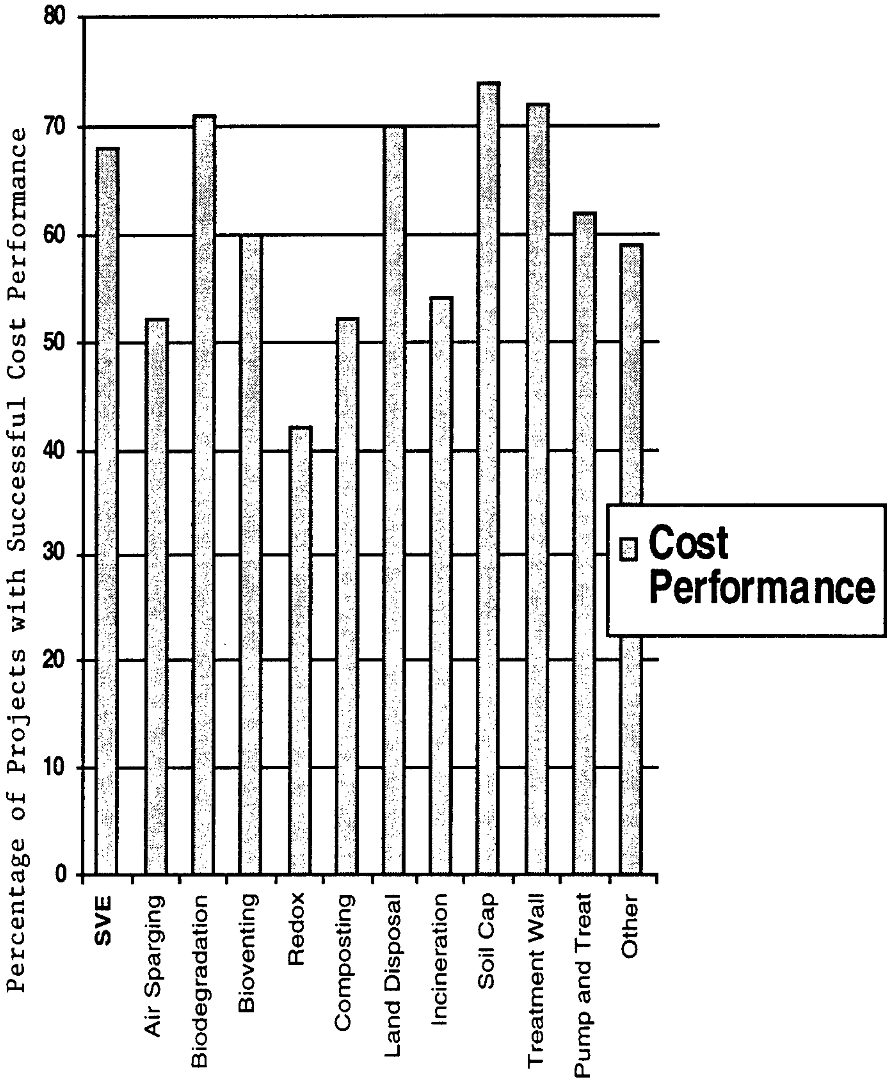

Figure 5.3.3. Suggested Analysis of Technology Selection and Cost Performance

In the area of correlating technology selection to results, the final recommendation is to compare technology selection to the attainment of regulatory goals. This analysis would conclude the series of tests to see if the technology selected met the project goals (see Figure 5.3.5). With this information in hand, the

researcher could then evaluate the validity of the first two research hypotheses, which concern technology selection for remediation projects.

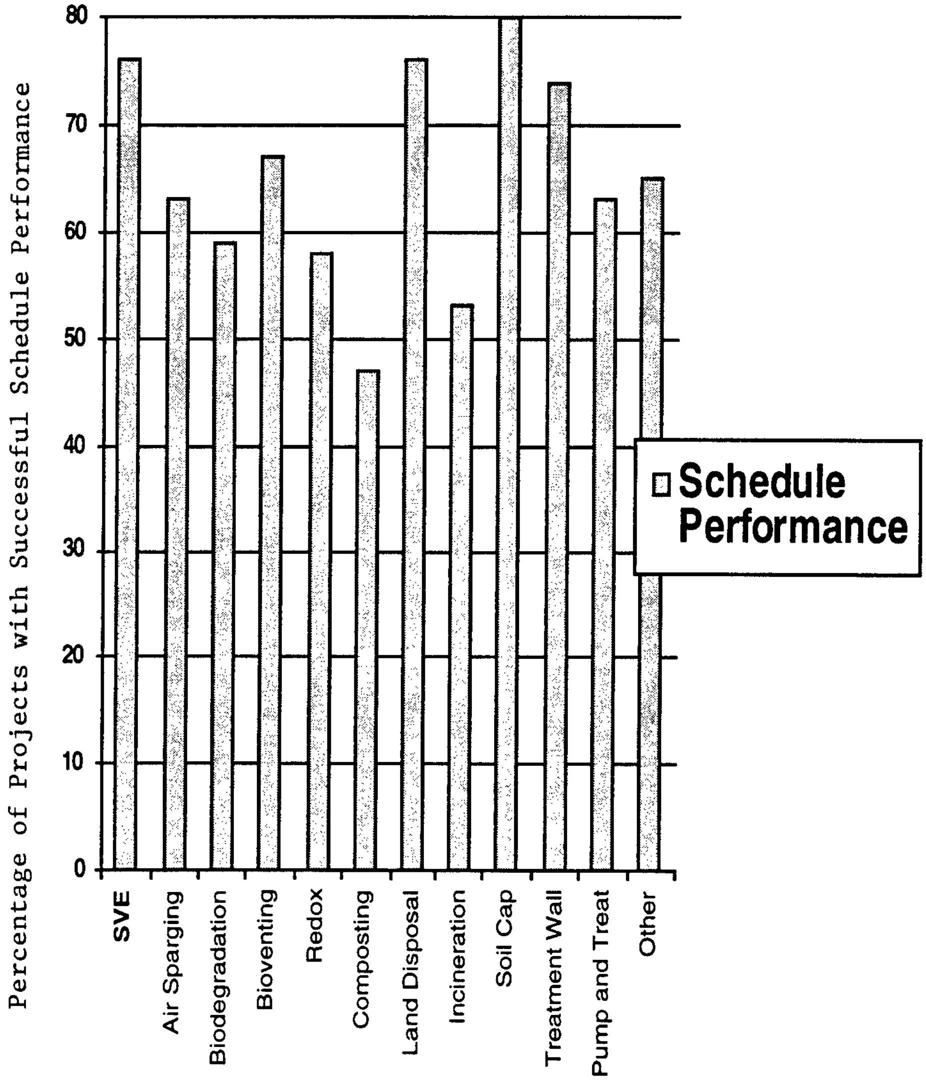

Figure 5.3.4. Suggested Analysis of Technology Selection and Schedule Performance

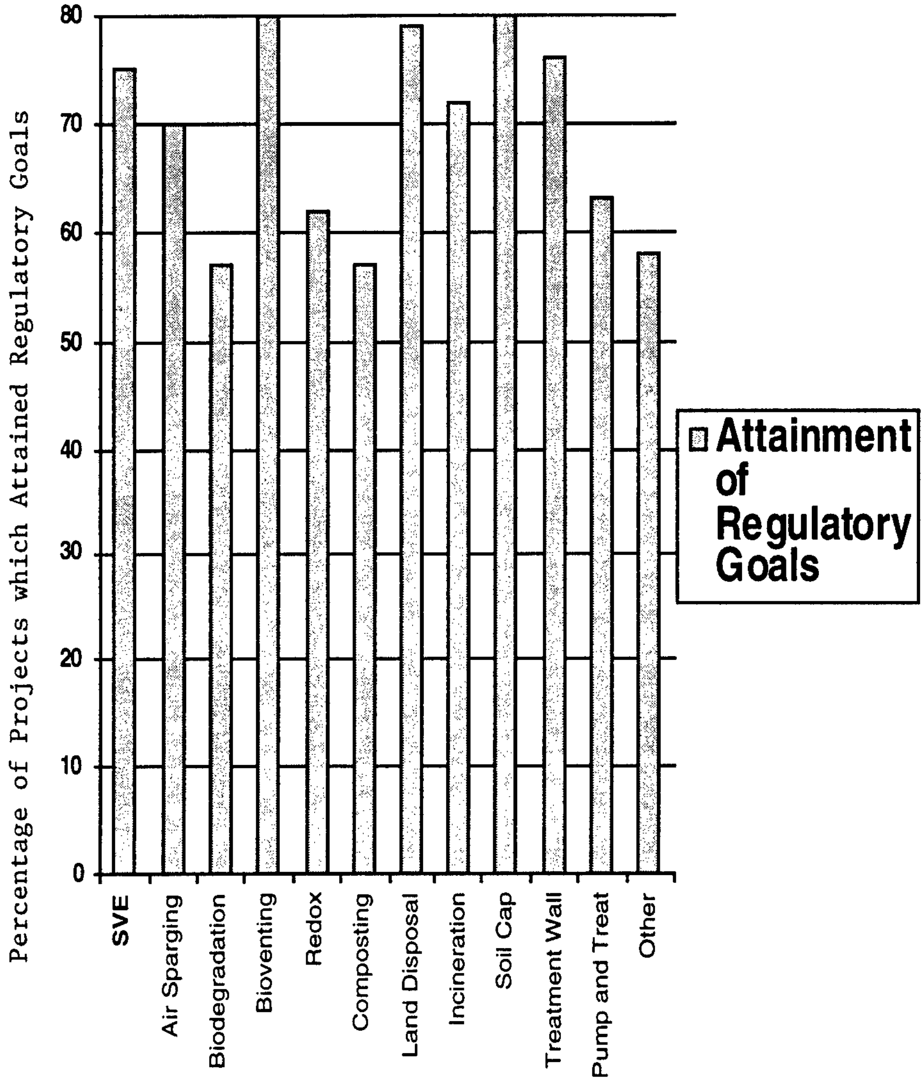

Figure 5.3.5. Suggested Analysis of Technology Selection and Attainment of Regulatory Remediation Goals

5.4. Impact of Contract Issues on Project Results

This suggested analysis would test the third research hypothesis:

- Contract types which assign all risk to the contractor or owner are less successful than risk sharing contractual arrangements; and

This analysis is similar to those in the previous section, except that instead of relating technology selection to project results, one would examine the relationship between contract issues and project results. The contract issues to be considered would be contract type and management structure (design and construction arrangements). The results areas to examine would be the answers to the "key factors" questions on contract type, incentives, and penalties, team building, and contractor performance, in addition to the overall project results, and cost and schedule performance. Sample diagrams of this analysis are shown in Figures 5.4.1 and 5.4.2. Before this analysis can be accomplished, the researcher must assign scores to the possible answers to the "key factors in project outcome" questions. A suggested scoring system follows: for "1- Success," assign a score of 80%, for "2- No Major Impact," assign a value of 50%, for "3- Failure," assign a score of 20%, and for questions that were answered with "4- Not Applicable," these data points should be excluded from the analysis.

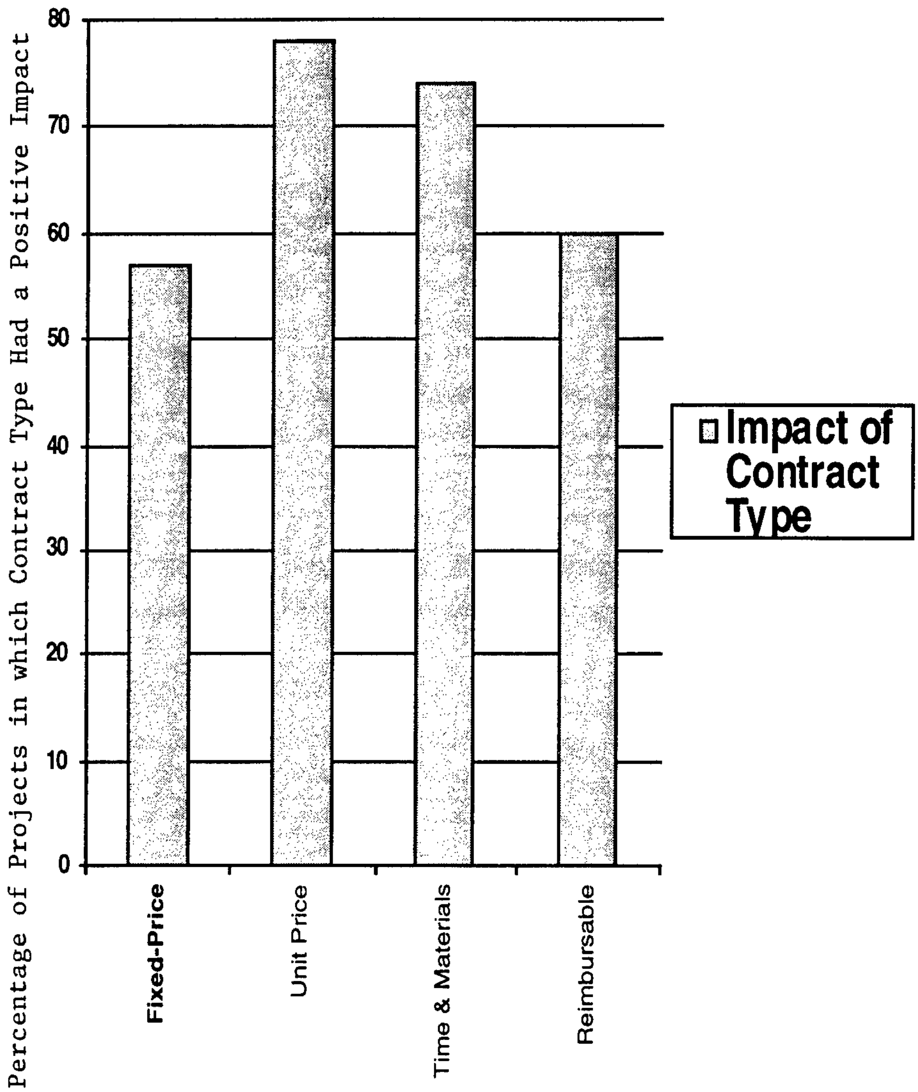

Figure 5.4.1. Suggested Analysis of Impact of Contract Type

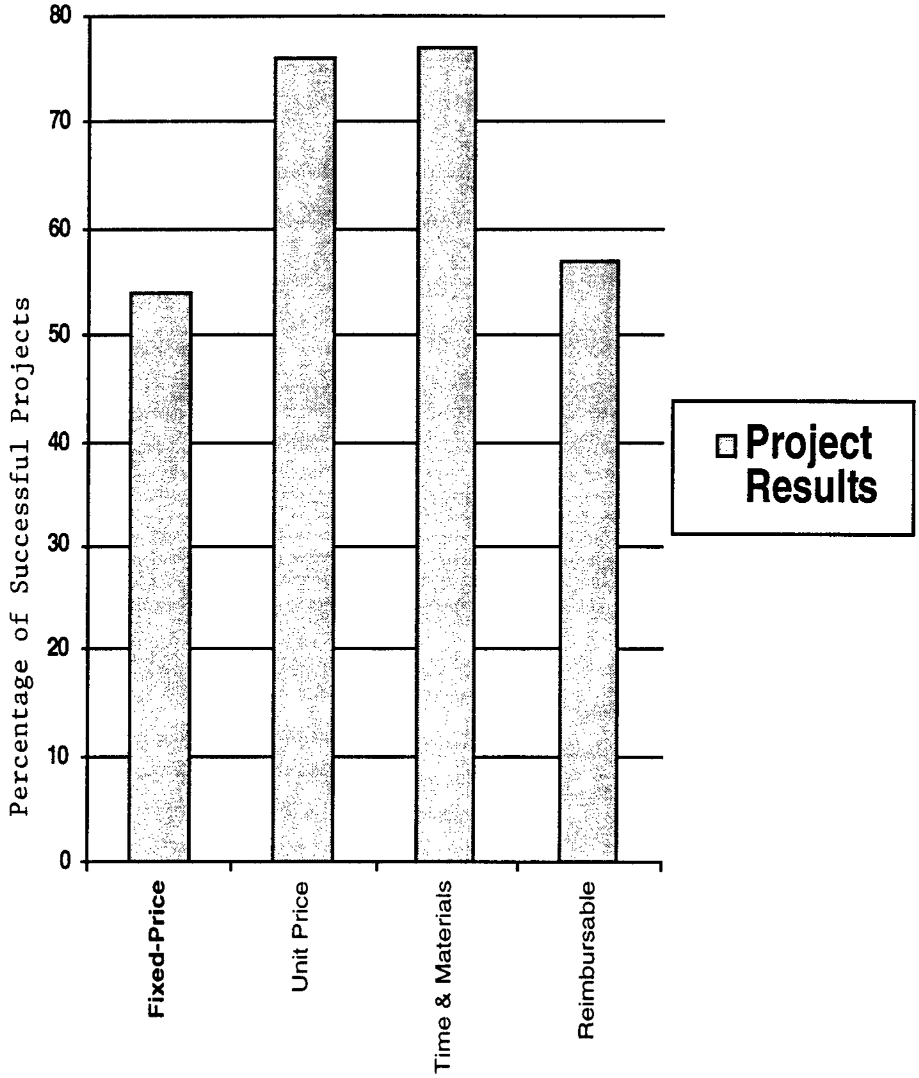

Figure 5.4.2. Suggested Analysis of Contract Type versus Project Results

5.5. Comparison of Percentage of Cost Spent on Study and Results

The fourth research hypothesis was:

- One reaches a point of diminishing returns in site characterization and study, beyond which project success does not improve.

To determine if there is a such a point, the answers to the question related to percentage of total project cost spent on site study would be correlated to scope change, cost and schedule performance, and overall project results. Two examples of these analyses are shown in Figures 5.5.1 and 5.5.2. To perform these analyses, values must be assigned to the possible answers to the questions concerning scope change, cost and schedule performance. Suggested values for the scope change question are 20% for "scope increased 5% or more," 50% for "no change," and 80% for "scope reduced 5% or more."

Several managers did not provide data in response to this question. From the initial review of the data collected to date, it appears that there may be insufficient information to make this determination. However, if the data permitted this analysis, it could provide important information to project planners.

Even if there is not enough data to determine the percentage of total project cost spent on site study, answers to the questions about project planning and sampling plan could be correlated to scope change and overall project results.

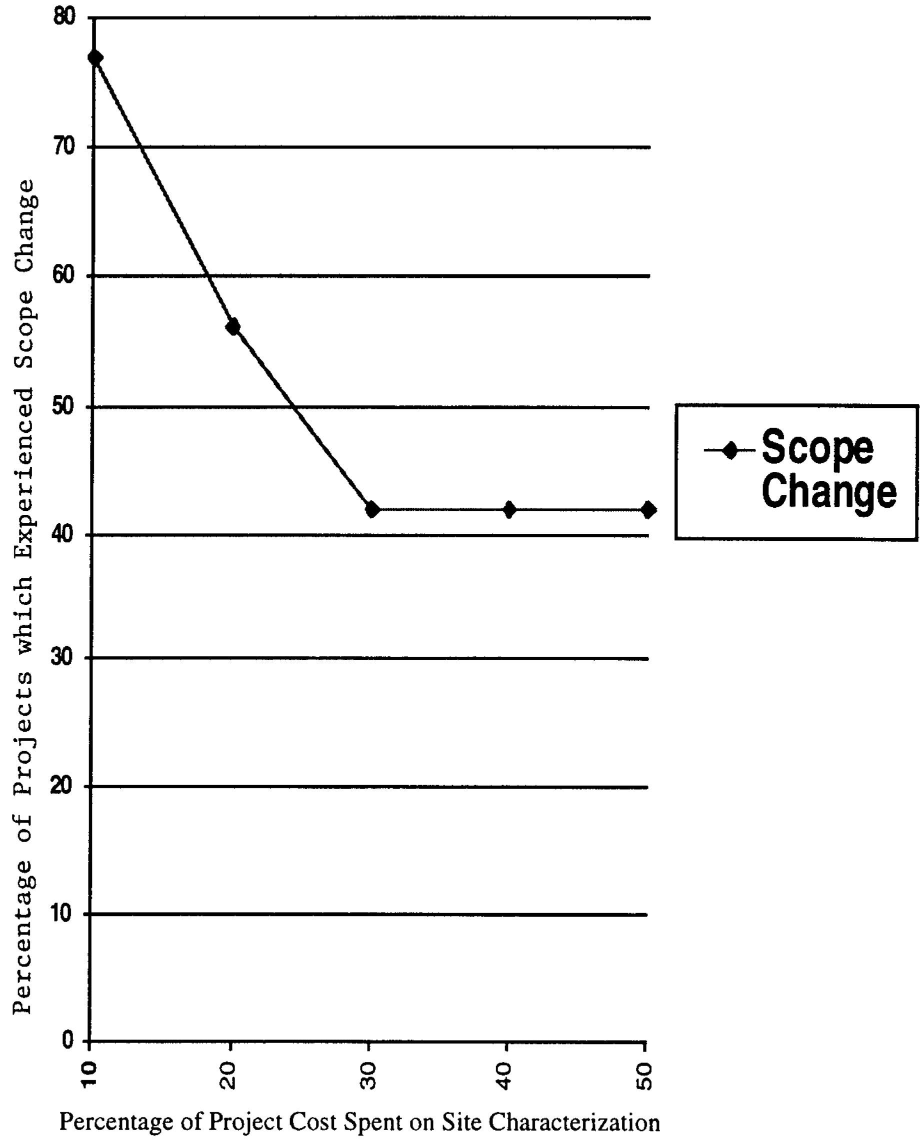

Figure 5.5.1. Suggested Analysis of Percentage of Project Cost Spent on Study and Scope Change

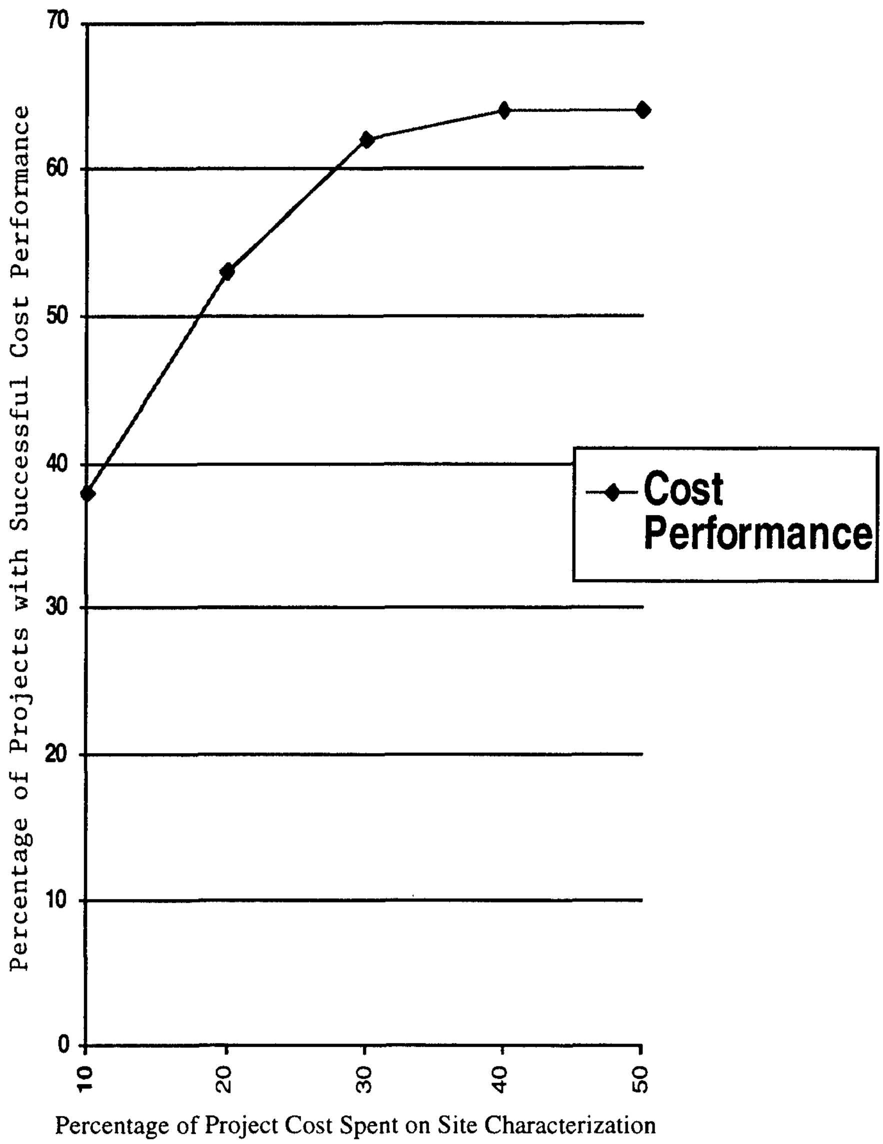

Figure 5.5.2. Suggested Analysis of Percentage of Project Cost Spent on Study and Cost Performance

5.6. Other Analysis

The survey was designed to be brief at only two pages long. Even in this short survey, however, more information was collected than the minimum answers required to test the research hypotheses. The additional information collected, which includes applicable remediation standards, reasons for technology selection, remediation contract cost, operations and maintenance costs, partnering, contract disputes, the impact of *force majeure*, funding, and political involvement could also be analyzed for useful correlations in this study or in future research.

Chapter 6. Conclusions and Recommendations

In roughly three decades, the environmental remediation business has become one of the nation's major industries. Current projections are that this work will cost over a trillion dollars during the coming years. Project management and remediation technology selection for hazardous waste contaminated sites are important and complex processes. The decisions made during these processes have a great impact on the cost and schedule of the environmental restoration project and affect the ultimate level of success achieved by the project.

6.1. Conclusions

This thesis, Part I of the research project, was designed to explore the areas of technology selection and project management in environmental remediation projects in the U.S. Air Force. Following an extensive literature review, a data collection tool was designed to gather information related to these issues of project management of environmental remediation. Then data were collected on 35 projects, and a relational database was designed and implemented. Part II of the research project will involve data collection from U.S. Navy project managers, enhancement of the relational database, and analysis of all of the data collected. In Part II, the research hypotheses developed in this thesis will be tested against the data.

According to the literature, there are two main areas in which project management can improve the outcome of environmental remediation projects. These two areas are technology selection and contract type for assignment of risk. The technology selection decision is difficult due to the high level of uncertainty in underground site conditions, complex regulatory requirements, potential financial liability, diversity of site characteristics, and the wide array of treatment technologies available. The contract type decision is difficult as well due to the increased uncertainty in environmental projects. Contract types such as unit price, guaranteed maximum cost, and time and materials serve to share risk and yield better results with less cost overruns.

The goal of making the data collection tool simple and short enough to easily answer was accomplished. Survey participants reported that it took between 10 and 20 minutes to complete each survey. The number of completed surveys returned, 35, adequately met the needs of the researcher.

In the process of database design, the most difficult aspect was determining the relationships of the various tables. It is much more straightforward to design a database to capture information in which each survey respondent would give only one answer to each question. However, because the survey was designed for the convenience of the respondent, this provided a challenge in database design and development.

Through the process of creating this thesis, the author learned not only about environmental remediation technologies and project management factors, but also

about conducting research. Elements of this research apprenticeship included carrying out a literature review, formulating hypotheses, preparing a data collection instrument, collecting data, creating a relational database, and putting all of this together into a thesis.

6.2. Recommendations

Part II of this research study is expected to begin in September 1997. Specific recommendations for that research effort include slight revisions of the data collection tool, and suggestions for data analysis. The wording change recommendations in the survey are detailed in section 5.1.3. The data analysis recommendations are listed in sections 5.2 through 5.6. Basically, the data should be analyzed to test the research hypotheses. This will involve correlating project inputs such as type and depth of contamination, soil and groundwater characterizations, technology selection, contract type, project planning with project outputs such as effectiveness of remediation technology, cost and schedule performance, and overall project results.

As for recommendations to the environmental and project management professions, the author will have to defer to the data analysis phase of Part II of this research project. In the meantime, however, the findings of earlier researchers will be maintained: the increased uncertainty of environmental remediation projects requires careful consideration in the technology selection decision making process, and calls for innovative contracting strategies which share risk between contractors and owners.

Appendix A. Cover Letter and Data Collection Tool

COLLEGE OF ENGINEERING
THE UNIVERSITY OF TEXAS AT AUSTIN

Department of Civil Engineering · Austin, Texas 78712-1076
Construction Engineering & Project Management · (512) 471-3541

27 June 1997

Air Force Center for Environmental Excellence
Attn: Environmental Program Manager
3207 North Road
Brooks AFB, TX 78235-5363

Dear Program Manager:

I am writing to request your assistance with an on-going research activity at the University of Texas at Austin (UT) into the management of hazardous waste site remediation projects. In a current research project, I am examining technology selection decisions and project risks in environmental projects. Professor James T. O'Connor, PE, is my supervisor in this research effort.

Would you please take 10-15 minutes per form to complete the attached survey forms for up to three environmental remediation projects with which you are familiar (one project per form). If you are unsure of a specific answer, just make an approximation or skip that particular question. Since we hope to collect information on a wide range of projects, we ask that you select three projects with differing outcomes. Ideally, we'd like you to provide data for one highly successful project, one typical project, and one project with results below your expectations.

Your participation in this survey is, of course, voluntary. In return for your support by filling out project survey forms, we can offer you a disk copy of the Microsoft Access database. Let us know by checking the appropriate block on the back of the form if you would like a copy of the database on a floppy disk. Thank you for your assistance.

Sincerely,

Scot T. Allen, Capt, USAF
Master of Science Candidate

Attached:
Project Information Surveys

Please fill out and return to: Capt Scot T. Allen
Department of Civil Engineering, CEPM
The University of Texas
Austin TX 78712-1076

Tel: (512) 454-4228
E-mail: allen.s@mail.utexas.edu
Fax: (512) 471-3191

Hazardous Waste Site Remediation Project Survey

Name: ____________ Fax: ____________ Date: ______

Agency/Unit: ____________ Project Name: ____________

Telephone: ____________ Project Location (Base, City, State): ______

E-mail: ____________ ____________

The Problem:

Contaminants present (check all that apply):

- ❑ Fuel hydrocarbons
- ❑ Chlorinated solvents
- ❑ Metals
- ❑ PCB's
- ❑ Other: ____________

Maximum depth of contamination:

- ❑ 0-10 feet
- ❑ 11-20 feet
- ❑ 21-30 feet
- ❑ 31-40 feet
- ❑ 41-50 feet
- ❑ Over 50 feet

Contamination has affected (all that apply):

- ❑ Soil
- ❑ Groundwater
- ❑ Air

If groundwater is affected, contaminants are (check all that apply):

- ❑ Dissolved in groundwater
- ❑ Free product (Non-Aqueous Phase Liquid, NAPL)

If groundwater is affected, the plume:

- ❑ extends beyond the property line
- ❑ is completely on site
- ❑ has an unknown extent

Average depth to the water table:

- ❑ 0-10 feet
- ❑ 11-20 feet
- ❑ 21-30 feet
- ❑ 31-40 feet
- ❑ 41-50 feet
- ❑ Over 50 feet

Soil/geology classification (check the most important site features):

- ❑ Tight clay/silt (impermeable soils)
- ❑ Loose sand/gravel (permeable soils)
- ❑ Relatively impermeable bedrock (e.g. solid granite)
- ❑ Permeable bedrock (e.g. fissured limestone)

Site is planned for reuse:

- ❑ In 1-3 years
- ❑ In 4-10 years
- ❑ No definite plans (or no information)

The Solution:

Remediation technology selected (please indicate combinations):

- ❑ Soil vapor extraction (SVE)
- ❑ Air sparging (*in situ*)
- ❑ Biodegradation (except bioventing)
- ❑ Bioventing
- ❑ Chemical Oxidation/Reduction
- ❑ Composting or Land Farming
- ❑ Excavation and land disposal
- ❑ Excavation and incineration
- ❑ Low Permeability Soil Cap
- ❑ Passive Treatment Wall
- ❑ Pump and treat (*ex situ* air stripping)
- ❑ Other: ____________ ____________

Applicable clean-up standards:

- ❑ Non-detect level
- ❑ Background level
- ❑ Risk based clean-up level
- ❑ Federal or state remediation standard

Primary reasons this technology (or combination) was selected:

- ❑ Air Force guidance
- ❑ Cost
- ❑ Schedule
- ❑ Regulatory requirements
- ❑ Effectiveness
- ❑ Minimal exposure hazard
- ❑ Other: ____________

Source(s) of funding:
- ❑ Base realignment and closure (BRAC)
- ❑ Installation Restoration Program (IRP)
- ❑ Defense Environmental Restoration Account (DERA)
- ❑ Other: ________________

The Contract:

Type of remediation implementation contract:
- ❑ Firm fixed-price (lump sum)
- ❑ Cost reimbursable (cost plus)
- ❑ Unit price
- ❑ Other: ________________

Estimated total contract cost amount (investigation, implementation, monitoring):

____

Implementation contract project duration (months): ________________

Design and construction were done by:
- ❑ Separate contracts
- ❑ In-house design and separate construction contract
- ❑ Design-build contract

What percentage of the implementation project has been completed to date:
- ❑ 0-25%
- ❑ 26-50%
- ❑ 51-75%
- ❑ 76-100 %
- ❑ Project complete

Results to Date:

Project scope change during project:
- ❑ Increased (5% or more)
- ❑ No change
- ❑ Reduced (5% or more)

Project cost:
- ❑ Under budget (2% or more)
- ❑ On budget
- ❑ Over budget (2% or more)

Anticipated or actual annual operations and maintenance (O&M) cost: ________

Percentage of total project cost spent on site characterization and study: ________

Schedule performance:
- ❑ Ahead of schedule (2% or more)
- ❑ On schedule
- ❑ Behind schedule (2% or more)

Project met (or is meeting) regulatory remediation goals:
- ❑ Yes
- ❑ No

Key factors in project outcome (1-Success, 2-No major impact, 3-Failure, 4-N/A):

	1	2	3	4
Project planning	❑	❑	❑	❑
Sampling plan/methods	❑	❑	❑	❑
Laboratory analysis	❑	❑	❑	❑
Implementation contract type	❑	❑	❑	❑
Contract incentives	❑	❑	❑	❑
Contract penalties	❑	❑	❑	❑
Team building/partnering	❑	❑	❑	❑
Contractor performance	❑	❑	❑	❑
Contract disputes	❑	❑	❑	❑
Discovered more contamination	❑	❑	❑	❑
Unanticipated soil, geological, or groundwater conditions	❑	❑	❑	❑
Technology performance	❑	❑	❑	❑
Severe weather (*force majeure*)	❑	❑	❑	❑
Funding	❑	❑	❑	❑
Political involvement	❑	❑	❑	❑
Other: ________	❑	❑	❑	❑

Evaluation of overall project results to date:
- ❑ Successful
- ❑ Acceptable
- ❑ Unsuccessful

Do you want a disk copy of the Microsoft Access for Windows database? ❑ Yes ❑ No

Other comments on the project (or any of the questions above):

Please recommend another person who could contribute to this research by filling out project information surveys:

Name: E-mail: Tel:

Address: Fax:

Appendix B. Data Collected

Proj ID	Project Name	Respondent	Base	City	State
5	Small Arms Firing Range	1	Bergstrom AFB	Austin	TX
6	Oil Water Separator Removal	1	Bergstrom AFB	Austin	TX
7	Air Injection/Soil Vapor Extraction	8	Bergstrom AFB	Austin	TX
8	Landfills 3-7	1	Bergstrom AFB	Austin	TX
9	Facility 4537, JP8 PST Removal	1	Bergstrom AFB	Austin	TX
10	Base Boundary Pump and Treat	4	Norton AFB	Sacramento	CA
11	Site 1 Removal Action	4	Norton AFB	Sacramento	CA
12	TCE Soil Vapor Extraction	4	Norton AFB		CA
13	Excavate Landfill 5	5	Pease AFB		NH
14	Hydrant System Removal	5	Pease AFB		NH
15	Hydrant System Site Characterization	5	Pease AFB		NH
16	Site 8 Remedial Action	5	Pease AFB		NH
17	Spill Site 10	5	Plattsburgh AFB		NY
18	Boundary Area Hydraulic Containment Sys	6	Lowry AFB	Denver	CO
19	Reactive Wall	6	Lowry AFB	Denver	CO
20	Source Area TCE Plume	6	Lowry AFB	Denver	CO
21	Bioventing at Sites STO 7 and STO 9	6	Lowry AFB	Denver	CO
22	Landfill Cap (OU 2)	6	Lowry AFB	Denver	CO
23	Fire Training Area #2	7	Chanute AFB	Rantoul	IL
24	Building 700 groundwater	7	Chanute AFB	Rantoul	IL
25	Low Level Radioactive Waste Removal	8	Bergstrom AFB	Austin	TX
26	Area 1 TCE Plume	9	Bergstrom AFB	Austin	TX
27	SWMU 9 Fire Department Training Area	9	Bergstrom AFB	Austin	TX
28	SWMU 121/205 Firing Ranges	9	Bergstrom AFB	Austin	TX
29	Site 29, SVE for Vadose Zone	10	Mather AFB		CA
30	Landfills 2-6	10	Mather AFB		CA

Table: Projects

Comments
At conclusion of remediation contract, no further action required, so there is no O&M cost.
Treatment system is operational and is controlling plume. O&M to continue until levels of TCE are below MCL.
Landfill wastes must be excavated to eliminate contact with groundwater and capped.
Project scope: remove 52 - 50,000 gal underground storage tanks (USTs) and 10 - 2,000 gal USTs and contaminated soil
Site characterization with goal of natural attenuation. Former hydrant system was within 100 feet of a public water well.
Need to contain plume and remediate site quickly as it is located in a National Register of Historic Places site.
Originally scoped as SVE system. Changed to excavation because of supposed high water table.
Contract cost amount does not include investigation.
Very successful project, a model for other bases. Contract cost amount does not include investigation.

Table: Projects (Continued)

Proj ID	Project Name	Respondent	Base	City	State
31	Site 32, UST	10	Mather AFB		CA
32	Unnamed Stream	11	Carswell AFB	Ft. Worth	TX
33	SVE at IRP sites 1, 2, 3	12	AFP 44	Tucson	AZ
34	Hazardous Waste Storage Area Closure	13	Griffiss AFB	Rome	NY
35	Remove USTs	13	Griffiss AFB	Rome	NY
36	Site 1	14	Vandenburg AFB		CA
37	Auto Hobby Shop Soils	6	Lowry AFB	Denver	CO
38	Site 29, SVE/Bioventing	15	Mather AFB		CA
39	990/996	16	Homestead AFB	Homestead	FL

Table: Projects (Continued)

Comments
Depth of contamination was greater than excavation capability. Contract cost amount does not include investigation.
SVE system works fine, but resin vapor system innovative technology has caused several problems.

Table: Projects (Continued)

ProjectID	ContaminationDepth	ExtentOfPlume	WaterTableDepth	SiteReuse
5	21-30 feet		11-20 feet	In 1-3 years
6	11-20 feet		21-30 feet	In 1-3 years
7	21-30 feet	is completely on site	11-20 feet	In 1-3 years
8	11-20 feet		21-30 feet	In 1-3 years
9	21-30 feet		21-30 feet	In 1-3 years
10	Over 50 feet	extends beyond the property line	Over 50 feet	In 1-3 years
11	31-40 feet			In 1-3 years
12	Over 50 feet	extends beyond the property line	Over 50 feet	In 1-3 years
13	11-20 feet	is completely on site	0-10 feet	No definite plans (or no information)
14	11-20 feet	is completely on site	0-10 feet	In 1-3 years
15	21-30 feet	is completely on site	0-10 feet	In 1-3 years
16	21-30 feet	extends beyond the property line	0-10 feet	No definite plans (or no information)
17	0-10 feet	is completely on site	0-10 feet	No definite plans (or no information)
18	21-30 feet	extends beyond the property line	11-20 feet	In 1-3 years
19	21-30 feet	extends beyond the property line	11-20 feet	In 1-3 years
20	31-40 feet	extends beyond the property line	11-20 feet	In 1-3 years
21	11-20 feet	is completely on site	11-20 feet	In 1-3 years
22	11-20 feet		11-20 feet	In 1-3 years
23	11-20 feet	is completely on site	0-10 feet	In 4-10 years
24	11-20 feet	is completely on site	0-10 feet	In 1-3 years
25	21-30 feet		21-30 feet	No definite plans (or no information)
26	Over 50 feet	extends beyond the property line	Over 50 feet	In 1-3 years
27	11-20 feet	is completely on site	21-30 feet	In 1-3 years
28	0-10 feet		21-30 feet	No definite plans (or no information)
29	Over 50 feet			In 1-3 years
30	Over 50 feet			No definite plans (or no information)

Table: Site Environmental Problems

ProjectID	ContaminationDepth	ExtentOfPlume	WaterTableDepth	SiteReuse
31	21-30 feet			In 4-10 years
32	0-10 feet		11-20 feet	In 1-3 years
33	Over 50 feet	extends beyond the property line	Over 50 feet	No definite plans (or no information)
34	0-10 feet		0-10 feet	No definite plans (or no information)
35	0-10 feet		11-20 feet	No definite plans (or no information)
36	11-20 feet	is completely on site	11-20 feet	No definite plans (or no information)
37	0-10 feet		11-20 feet	In 1-3 years
38	Over 50 feet		Over 50 feet	In 1-3 years
39	0-10 feet	is completely on site	0-10 feet	In 1-3 years

Table: Site Environmental Problems (Continued)

ProjectID	Hydrocarbons	Solvents	Metals	PCBs	Other	Explanation
5	☐	☐	☑	☐	☐	
6	☐	☑	☑	☐	☐	
7	☑	☐	☑	☐	☐	
8	☐	☐	☐	☐	☑	Uncharacterized landfills
9	☑	☐	☐	☐	☐	
10	☐	☑	☐	☐	☐	
11	☐	☑	☑	☐	☐	
12	☐	☑	☐	☐	☐	
13	☑	☑	☑	☐	☑	Pesticides
14	☑	☐	☐	☐	☐	
15	☐	☐	☐	☐	☐	
16	☑	☑	☑	☑	☐	
17	☑	☑	☐	☐	☐	
18	☐	☑	☐	☐	☐	
19	☐	☑	☐	☐	☐	
20	☐	☑	☐	☐	☐	
21	☑	☐	☐	☐	☐	
22	☐	☑	☐	☐	☑	Methane gas/landfill waste
23	☑	☐	☑	☑	☐	
24	☑	☐	☐	☐	☐	
25	☐	☐	☐	☐	☑	Low level radioactive waste
26	☐	☑	☐	☐	☐	
27	☑	☑	☐	☐	☐	
28	☐	☐	☑	☐	☐	
29	☐	☑	☐	☐	☐	
30	☐	☐	☐	☐	☑	Refuse

Table: Site Contaminants

ProjectID	Hydrocarbons	Solvents	Metals	PCBs	Other	Explanation
31	☑	☐	☐	☐	☐	
32	☑	☐	☑	☐	☐	
33	☐	☑	☐	☐	☐	
34	☐	☐	☐	☑	☐	
35	☑	☐	☐	☐	☐	
36	☑	☐	☐	☐	☐	
37	☑	☐	☐	☐	☐	
38	☑	☐	☐	☐	☐	
39	☑	☐	☐	☐	☐	

Table: Site Contaminants (Continued)

ProjectID	Soil	Groundwater	Air
5	☑	☐	☐
6	☑	☐	☐
7	☑	☑	☐
8	☑	☐	☐
9	☑	☐	☐
10	☐	☑	☐
11	☑	☐	☐
12	☑	☑	☐
13	☑	☑	☐
14	☑	☑	☐
15	☑	☑	☐
16	☑	☑	☐
17	☑	☑	☐
18	☑	☑	☐
19	☐	☑	☐
20	☐	☑	☐
21	☑	☑	☐
22	☑	☐	☐
23	☑	☑	☐
24	☑	☑	☐
25	☑	☐	☐
26	☐	☑	☐
27	☑	☑	☐
28	☑	☐	☐
29	☑	☐	☐
30	☑	☐	☐
31	☑	☐	☐
32	☑	☐	☐
33	☑	☑	☐
34	☑	☐	☐
35	☑	☐	☐
36	☑	☑	☐
37	☑	☐	☐
38	☑	☐	☐
39	☑	☑	☐

Table: Site Media

ProjectID	Dissolved	Free Product
7	☑	☑
10	☑	☐
12	☑	☐
13	☑	☐
14	☑	☑
15	☑	☑
16	☑	☑
17	☑	☐
18	☑	☑
19	☐	☑
20	☐	☑
21	☐	☑
22	☐	☑
23	☐	☑
24	☑	☐
26	☑	☐
27	☑	☐
33	☑	☐
36	☑	☐
39	☑	☑

Table: Site Groundwater

ProjectID	Tight Soils	Loose Soils	Impermeable Bedrock	Permeable Bedrock
5	☑	☐	☐	☐
6	☐	☑	☐	☐
7	☐	☑	☐	☐
8	☑	☐	☐	☐
9	☐	☑	☐	☐
10	☑	☑	☐	☐
11	☐	☑	☐	☐
12	☑	☑	☐	☐
13	☑	☑	☐	☑
14	☐	☑	☐	☐
15	☐	☑	☐	☐
16	☑	☑	☐	☑
17	☐	☑	☐	☐
18	☑	☐	☐	☐
19	☑	☐	☐	☐
20	☑	☐	☐	☐
21	☑	☐	☐	☐
22	☑	☐	☐	☐
23	☑	☑	☐	☐
24	☑	☐	☐	☐
25	☑	☐	☐	☐
26	☐	☑	☐	☐
27	☑	☐	☐	☐
28	☑	☐	☐	☐
29	☐	☑	☐	☐
30	☐	☑	☐	☐
31	☐	☑	☐	☐
32	☐	☑	☐	☐
33	☑	☐	☐	☐
34	☐	☑	☐	☐
35	☐	☑	☐	☐
36	☐	☑	☐	☐
37	☑	☐	☐	☐
38	☐	☑	☐	☐
39	☐	☐	☐	☑

Table: Site Geology

ProjectID	Soil Vapor Extr	Air Sparging	Biodegradation	Bioventing	Redox	Composting	Land Disposal
5	☐	☐	☐	☐	☐	☐	☑
6	☐	☐	☐	☐	☐	☐	☑
7	☑	☑	☐	☐	☐	☐	☐
8	☐	☐	☐	☐	☐	☐	☐
9	☐	☐	☐	☐	☐	☐	☑
10	☐	☐	☐	☐	☐	☐	☐
11	☐	☐	☐	☐	☐	☐	☑
12	☑	☐	☐	☐	☐	☐	☐
13	☐	☐	☐	☐	☐	☐	☑
14	☐	☐	☐	☐	☐	☐	☑
15	☐	☐	☐	☐	☐	☐	☐
16	☑	☐	☑	☐	☐	☐	☐
17	☐	☐	☐	☐	☐	☐	☑
18	☐	☐	☐	☐	☐	☐	☐
19	☐	☐	☐	☐	☐	☐	☐
20	☐	☐	☐	☐	☐	☐	☐
21	☐	☐	☐	☑	☐	☐	☐
22	☐	☐	☐	☐	☐	☐	☐
23	☐	☐	☐	☐	☐	☐	☑
24	☐	☐	☐	☐	☐	☐	☐
25	☐	☐	☐	☐	☐	☐	☑
26	☐	☐	☑	☐	☐	☐	☐
27	☐	☐	☐	☐	☐	☐	☑
28	☐	☐	☐	☐	☐	☐	☐
29	☑	☐	☐	☑	☐	☐	☐
30	☐	☐	☐	☐	☐	☐	☑

Table: Technology Selected

Incineration	Soil Cap	Treatment Wall	Pump and Treat	Other	Explanation
☐	☐	☐	☐	☐	
☐	☐	☐	☐	☐	
☐	☐	☐	☐	☐	
☐	☑	☐	☐	☐	
☐	☐	☐	☐	☑	Tanks recycled
☐	☐	☐	☑	☐	
☐	☐	☐	☐	☐	
☐	☐	☐	☐	☐	
☐	☑	☐	☐	☐	
☐	☐	☐	☐	☐	
☐	☐	☐	☐	☑	Site characterization
☐	☑	☐	☑	☐	
☑	☐	☐	☐	☐	
☐	☐	☐	☑	☐	
☐	☐	☑	☐	☐	
☐	☐	☐	☐	☑	Dual Phase Extraction
☐	☐	☐	☐	☐	
☐	☑	☐	☐	☐	
☐	☐	☐	☐	☑	Pipe removal
☐	☐	☐	☑	☐	
☐	☐	☐	☐	☐	
☐	☐	☐	☐	☐	
☐	☐	☐	☐	☐	
☐	☐	☐	☐	☑	Gravity Separation/Soil Washing
☐	☐	☐	☐	☐	
☐	☑	☐	☐	☐	

Table: Technology Selected (Continued)

ProjectID	Soil Vapor Ext	Air Sparging	Biodegradation	Bioventing	Redox	Composting	Land Disposal
31	☐	☐	☐	☐	☐	☑	☐
32	☐	☐	☐	☐	☐	☐	☑
33	☑	☐	☐	☐	☐	☐	☐
34	☐	☐	☐	☐	☐	☐	☑
35	☐	☐	☐	☐	☐	☐	☑
36	☐	☐	☑	☐	☐	☐	☐
37	☐	☐	☐	☐	☐	☐	☑
38	☑	☐	☐	☑	☐	☐	☐
39	☐	☐	☐	☐	☐	☐	☑

Table: Technology Selected (Continued)

Incineration	Soil Cap	Treatment Wall	Pump and Treat	Other	Explanation
☐	☐	☐	☐	☑	Excavated prior to composting
☐	☐	☐	☐	☐	
☐	☐	☐	☐	☑	Resin adsorption vapor treatment
☐	☐	☐	☐	☐	
☐	☐	☐	☐	☐	
☐	☐	☐	☐	☐	
☐	☐	☐	☐	☐	
☐	☐	☐	☐	☐	
☐	☐	☐	☐	☐	

Table: Technology Selected (Continued)

ProjectID	Non-detect	Background	Risk based	Fed or State
5	☐	☑	☐	☐
6	☐	☑	☐	☐
7	☐	☑	☑	☐
8	☐	☐	☑	☑
9	☐	☑	☐	☐
10	☐	☐	☐	☑
11	☐	☐	☑	☐
12	☐	☐	☐	☑
13	☐	☐	☐	☑
14	☑	☐	☐	☑
15	☐	☐	☐	☑
16	☐	☐	☐	☑
17	☐	☐	☐	☑
18	☐	☐	☐	☑
19	☐	☐	☐	☑
20	☐	☐	☐	☑
21	☐	☐	☐	☑
22	☐	☐	☑	☐
23	☐	☐	☑	☐
24	☐	☐	☐	☑
25	☐	☑	☐	☐
26	☐	☐	☑	☐
27	☐	☐	☑	☐
28	☐	☐	☑	☐
29	☐	☐	☐	☑
30	☐	☐	☐	☑
31	☐	☐	☐	☑
32	☐	☐	☑	☐
33	☐	☐	☐	☑
34	☐	☐	☐	☑
35	☑	☐	☐	☐
36	☐	☐	☐	☑
37	☐	☐	☑	☑
38	☐	☐	☑	☑
39	☐	☐	☐	☑

Table: Project Standards

Proj ID	Military	Cost	Schedule	Regulatory	Effectiveness	Min Exposure	Other	Comments
5	☐	☐	☑	☑	☐	☐	☑	Airport construction requirement
6	☐	☑	☑	☐	☑	☐	☐	
7	☐	☑	☑	☐	☑	☐	☐	
8	☐	☐	☐	☑	☑	☑	☐	
9	☐	☑	☐	☐	☐	☐	☐	
10	☐	☑	☐	☑	☐	☐	☑	EPA's Record of Decision (ROD)
11	☐	☑	☐	☑	☑	☐	☐	
12	☐	☑	☐	☑	☐	☐	☑	ROD
13	☐	☑	☐	☑	☑	☐	☑	Public input
14	☑	☑	☐	☑	☑	☐	☐	
15	☑	☑	☑	☑	☑	☑	☑	Airfield redevelopment
16	☑	☐	☐	☐	☑	☐	☑	Historic preservation of site
17	☐	☐	☐	☐	☑	☐	☐	
18	☐	☑	☐	☑	☑	☐	☐	
19	☐	☐	☐	☐	☐	☐	☑	Innovative technology
20	☐	☐	☐	☑	☑	☐	☐	
21	☑	☑	☐	☐	☑	☐	☐	
22	☐	☐	☐	☐	☐	☐	☑	EPA presumptive remedy
23	☐	☐	☑	☑	☐	☐	☑	Source removal
24	☐	☐	☐	☐	☑	☐	☐	
25	☐	☐	☐	☐	☑	☐	☐	
26	☐	☑	☐	☐	☐	☐	☐	
27	☐	☑	☐	☐	☑	☐	☐	
28	☐	☑	☐	☑	☐	☐	☐	
29	☐	☑	☐	☑	☑	☐	☐	
30	☐	☑	☐	☑	☐	☐	☐	

Table: Project Reasons

Proj ID	Military	Cost	Schedule	Regulatory	Effectiveness	Min Exposure	Other	Comments
31	☐	☑	☐	☑	☑	☐	☐	
32	☐	☑	☑	☐	☑	☐	☐	
33	☑	☐	☐	☐	☑	☐	☐	
34	☐	☐	☐	☑	☐	☐	☐	
35	☑	☐	☐	☐	☐	☐	☐	
36	☐	☑	☐	☐	☑	☐	☐	
37	☑	☑	☑	☑	☑	☐	☐	
38	☑	☑	☐	☑	☐	☐	☐	
39	☐	☐	☑	☐	☑	☐	☐	

Table: Project Reasons (Continued)

ProjectID	BRAC	IRP	DERA	Other
5	☑	☐	☐	☐
6	☑	☐	☐	☐
7	☑	☑	☐	☐
8	☑	☑	☐	☐
9	☑	☐	☐	☐
10	☑	☐	☐	☐
11	☑	☐	☐	☐
12	☑	☐	☐	☐
13	☑	☐	☐	☐
14	☑	☐	☐	☐
15	☑	☐	☐	☐
16	☑	☐	☐	☐
17	☑	☐	☐	☐
18	☑	☐	☐	☐
19	☑	☑	☐	☐
20	☑	☐	☐	☐
21	☑	☐	☐	☐
22	☑	☐	☐	☐
23	☑	☐	☐	☐
24	☑	☐	☐	☐
25	☑	☑	☐	☐
26	☑	☐	☐	☐
27	☑	☐	☐	☐
28	☑	☐	☐	☐
29	☑	☐	☐	☐
30	☑	☐	☐	☐
31	☑	☐	☐	☐
32	☑	☐	☐	☐
33	☐	☐	☑	☐
34	☑	☐	☐	☐
35	☑	☐	☐	☐
36	☐	☐	☑	☐
37	☑	☐	☐	☐
38	☑	☐	☐	☐
39	☑	☐	☐	☐

Table: Project Funding

ProjectID	ContractType	TotalCost	Duration	ManagementStructure	PercentComplete
5	Cost reimbursable (cost plus)	$0.00	7		Project complete
6	Cost reimbursable (cost plus)	$0.00	3		Project complete
7	Cost reimbursable (cost plus)	$4,518,700.00	18	Design-build contract	Project complete
8	Cost reimbursable (cost plus)	$0.00	36	Design-build contract	76-99%
9	Cost reimbursable (cost plus)	$0.00	12		76-99%
10	Firm, fixed price (lump sum)	$7,000,000.00	18	Design-build contract	76-99%
11	Firm, fixed price (lump sum)	$3,000,000.00	20	Design-build contract	76-99%
12		$0.00	0	Design-build contract	76-99%
13	Cost reimbursable (cost plus)	$6,680,000.00	19	Separate contracts	Project complete
14	Cost reimbursable (cost plus)	$6,910,000.00	24		Project complete
15	Time and materials	$3,100,000.00	18		Project complete
16	Cost reimbursable (cost plus)	$10,200,000.00	18	Design-build contract	Project complete
17	Cost reimbursable (cost plus)	$2,360,000.00	9	Design-build contract	76-99%
18	Cost reimbursable (cost plus)	$800,000.00	24	Separate contracts	26-50%
19	Firm, fixed price (lump sum)	$500,000.00	8	Design-build contract	76-99%
20	Cost reimbursable (cost plus)	$2,000,000.00	36	Separate contracts	26-50%
21	Cost reimbursable (cost plus)	$350,000.00	30	Separate contracts	76-99%
22		$15,000,000.00	20	Separate contracts	0-25%
23	Cost reimbursable (cost plus)	$250,000.00	6	In-house design & construction	76-99%
24	Cost reimbursable (cost plus)	$274,000.00	18	In-house design & construction	76-99%
25	Firm, fixed price (lump sum)	$175,500.00	3	Design-build contract	Project complete
26	Cost reimbursable (cost plus)	$0.00		Separate contracts	76-99%
27	Cost reimbursable (cost plus)	$1,500,000.00	3	Separate contracts	0-25%
28	Cost reimbursable (cost plus)	$800,000.00	5	Separate contracts	51-75%
29	Cost reimbursable (cost plus)	$938,900.00	72	Design-build contract	51-75%
30	Cost reimbursable (cost plus)	$10,200,000.00	30	Design-build contract	Project complete

Table: Contract Type and Issues

ProjectID	ContractType	TotalCost	Duration	ManagementStructure	PercentComplete
31	Cost reimbursable (cost plus)	$431,400.00	18	Design-build contract	Project complete
32	Cost reimbursable (cost plus)	$517,000.00	0	Separate contracts	51-75%
33	Cost reimbursable (cost plus)	$6,300,000.00	8	Design-build contract	76-99%
34	Cost reimbursable (cost plus)	$3,500,000.00	24		0-25%
35	Cost reimbursable (cost plus)	$2,500,000.00	10		51-75%
36	Time and Materials	$450,000.00	24		76-99%
37	Cost reimbursable (cost plus)	$400,000.00	16	Separate contracts	76-99%
38	Cost reimbursable (cost plus)	$1,000,000.00	0	Separate contracts	51-75%
39	Cost reimbursable (cost plus)	$800,000.00	7	Design-build contract	76-99%

Table: Contract Type and Issues (Continued)

Proj ID	Scope Change	Cost Performance	O & M Cost	% Study	Schedule Performance
5	Increased (5% or more)	Over budget (2% or more)	$0.00	37	Ahead of schedule (2% or more)
6	No change	On budget	$0.00	0	On schedule
7	No change	On budget	$0.00	0	Behind schedule (2% or more)
8	Increased (5% or more)	Over budget (2% or more)	$0.00	0	Behind schedule (2% or more)
9	Increased (5% or more)	Over budget (2% or more)	$0.00	0	On schedule
10	Increased (5% or more)		$1,000,000.00	0	On schedule
11	Increased (5% or more)	On budget	$0.00	25	On schedule
12	Increased (5% or more)	On budget	$0.00	0	On schedule
13	No change	Under budget (2% or more)	$150,000.00	0	Ahead of schedule (2% or more)
14	No change	On budget	$0.00	0	On schedule
15	No change	On budget	$0.00	100	On schedule
16	No change	On budget	$815,500.00	20	On schedule
17	Increased (5% or more)	Over budget (2% or more)	$0.00	5	Behind schedule (2% or more)
18	No change	On budget	$260,000.00	25	On schedule
19	No change	On budget	$0.00	20	On schedule
20	No change	On budget	$260,000.00	28	On schedule
21	No change	Over budget (2% or more)	$100,000.00	25	On schedule
22	Increased (5% or more)	Over budget (2% or more)	$500,000.00	2	Behind schedule (2% or more)
23	Reduces (5% or more)	Under budget (2% or more)	$0.00	0	Ahead of schedule (2% or more)
24	No change	Under budget (2% or more)	$0.00	0	Ahead of schedule (2% or more)
25	No change	Under budget (2% or more)	$0.00	19	Behind schedule (2% or more)
26	Increased (5% or more)	On budget	$1,500,000.00	0	On schedule
27	No change	On budget	$0.00	20	On schedule
28	No change	On budget	$0.00	50	On schedule
29	No change	On budget	$240,000.00	0	On schedule
30	Increased (5% or more)	Under budget (2% or more)	$276,000.00	0	Ahead of schedule (2% or more)

Table: Project Results

Met Goals	Planning	Sampling	Lab Analysis	Contract	Incentives	Penalties	Team Building	Contractor
☑	1	2	2	1	1	2	4	1
☑	1	1	1	2	2	2	1	1
☑	1	1	1	2	1	1	3	1
☑	1	1	1	4	1	1	1	1
☑	1	1	1	2	2	2	1	1
☑	1	2	2	2	2	2	2	1
☑	1	1	1	2	2	2	2	1
☑	1	3	2	2	2	2	2	1
☑	1	2	2	1	4	4	2	1
☑	1	1	1	1	4	4	1	1
☑	1	1	1	1	4	4	1	1
☐	1	2	2	1	4	4	1	1
☑	3	3	2	2	4	4	3	3
☑	1	1	2	2	2	2	1	2
☑	1	1	1	1	1	1	1	1
☑	1	1	1	2	2	2	1	2
☑	1	1	2	2	2	2	1	2
☑	2	2	2	2	2	2	1	2
☑	1	1	1	1	1	4	1	1
☑	1	1	1	1	1	4	1	1
☑	2	1	1	1	4	4	2	1
☑	1	1	1	1	2	2	1	1
☐	1	1	2	2	2	2	1	1
☑	1	2	2	2	2	2	1	1
☐	1	1	1	1	2	4	1	1
☑	1	2	2	1	2	4	1	1

Table: Project Results (Continued)

Disputes	Contamination	Site Conditions	Technology	Weather	Funding	Politics	Overall
4	4	2	1	4	4	1	Acceptable
4	3	4	1	2	2	2	Successful
3	3	2	1	2	2	2	Acceptable
4	2	4	1	3	3	3	Successful
4	3	3	1	4	4	3	Acceptable
2	2	3	1	2	2	2	Successful
2	3	3	2	2	2	2	Acceptable
2	2	2	1	2	2	2	Successful
4	2	1	4	4	1	4	Successful
4	2	4	4	4	1	4	Successful
4	2	4	4	4	1	4	Successful
4	2	4	1	4	1	1	Successful
4	3	3	4	4	4	4	Acceptable
2	2	2	2	2	2	2	Successful
2	2	2	1	2	1	2	Successful
2	2	2	2	2	2	2	Successful
2	2	2	2	2	1	2	Acceptable
2	2	2	2	2	2	2	Acceptable
4	1	4	1	4	1	4	Successful
4	2	4	1	4	1	4	Successful
4	4	1	1	4	1	2	Successful
2	2	2	1	2	2	3	Successful
2	4	2	4	4	4	2	Successful
2	2	2	1	2	2	2	Successful
4	2	4	1	4	4	4	Successful
4	2	4	1	4	4	4	Successful

Table: Project Results (Continued)

Proj ID	Scope Change	Cost Performance	O & M Cost	% Study	Schedule Performance
31	Increased (5% or more)	Over budget (2% or more)	$0.00	0	Behind schedule (2% or more)
32	Reduces (5% or more)	Under budget (2% or more)	$0.00	68	On schedule
33	Increased (5% or more)	On budget	$0.00	0	On schedule
34	Increased (5% or more)	On budget	$0.00	20	On schedule
35	Reduces (5% or more)	Under budget (2% or more)	$0.00	10	On schedule
36	Increased (5% or more)	On budget	$25,000.00	55	Ahead of schedule (2% or more)
37	Increased (5% or more)	Over budget (2% or more)	$0.00	25	Behind schedule (2% or more)
38	No change	On budget	$240,000.00	30	On schedule
39	No change	On budget	$200,000.00	0	On schedule

Table: Project Results (Continued)

Met Goals	Planning	Sampling	Lab Analysis	Contract	Incentives	Penalties	Team Building	Contractor
☑	3	2	2	4	4	4	4	1
☑	1	1	1	1	4	4	1	1
☐	1	2	1	1	4	4	1	1
☑	1	2	2	1	2	2	1	1
☑	1	2	2	1	1	1	1	1
☑		1	1	1	4	4	1	1
☑	2	1	2	1	1	2	1	2
☑	1	2	1	1	2	4	4	1
☑	2	2	2	2	2	2	2	2

Table: Project Results (Continued)

Disputes	Contamination	Site Conditions	Technology	Weather	Funding	Politics	Overall
4	3	3	4	3	4	4	Acceptable
4	4	2	1	2	1	2	Successful
4		2	3	2	1	4	Acceptable
2	1	2	2	2	2	4	Acceptable
2	1	2	2	2	2	4	Successful
4	2	2	1	4	1	4	Successful
2	1	2	1	2	1	2	Acceptable
4	1	22	1	4	1	4	Successful
2	2	2	1	2	2	2	Successful

Table: Project Results (Continued)

Appendix C. Bibliography

Abbasi, R. A. (February 1996). "Ground-Water Treatments Gain Ground," *Civil Engineering*, Vol. 96 (2), p. 53-55.

Air Force Center For Environmental Excellence (AFCEE). (March 1994). "AFCEE Remediation Matrix: Hierarchy of Preferred Alternatives," AFCEE, Brooks Air Force Base, San Antonio, TX.

Air Force Center For Environmental Excellence (AFCEE). (June 1996). "Bioventing Performance and Cost Results from Multiple Air Force Test Sites," AFCEE Technology Transfer Division, Brooks Air Force Base, San Antonio, TX.

Air Force Center For Environmental Excellence (AFCEE). (June 1994). Use of Risk-Based Standards for Cleanup of Petroleum Contaminated Soil. AFCEE, Armstrong Laboratory, Brooks Air Force Base, San Antonio, TX, and Air Force Institute of Technology, Wright-Patterson Air Force Base, Dayton, OH.

Bartell, R. P.; Timothy; O'Rourke, S.; and Kanaras, L. (August 1993). "Technology Demonstration and Evaluation," *The Military Engineer*, Vol. 85 (558), p. 6-8.

Bell, David C. (1995). Stakeholder Involvement in the Risk Management of Environmental Restoration Programs. University of California, Los Angeles, CA.

Blackburn, J. W.; Robbins, W. K.; Prince, R. C.; Harner E. J.; Clark, J. R.; Atlas, R. M.; and Wilkinson, J. B. (March 1993). "Experimental Comparisons in Petroleum Site Remediation," American Chemical Symposium on Bioremediation and Bioprocessing Presented at the 205th National Meeting of the American Chemical Society (ACS), 28 March - 2 April 1993. ACS, p. 254-259.

Bosetti, Timothy G. (1997). Low Temperature Thermal Desorption Projects in U.S. Army Corps of Engineers. The University of Texas at Austin, TX.

Clemen, Robert T. (1996). Making Hard Decisions: an Introduction to Decision Analysis, 2nd edition. Duxbury Press, Wadsworth Publishing Company, Belmont, CA.

The Construction Industry Institute (CII). (October 1995). "Environmental Remediation," Published by CII, Austin, TX, Research Summary 48-1.

Dakins, M. E. (1994). Modeling for Risk-based Environmental Remediation Decision-Making. State University of New York, NY.

Daniel, Vijay. (1996). Design of a Relational Database for Texas Department of Transportation to Track Contractual Information. The University of Texas at Austin, TX.

Department of Defense (DOD) Environmental Technology Transfer Committee, Federal Remediation Technologies Roundtable. (1994). Remediation Technologies Screening Matrix and Reference Guide. National Technical Information Service, Washington, DC.

Donnelly, J. R. and Webster, W. C. (May 1996). "From Sediment to Solid," *Civil Engineering*, Vol. 96 (5), p. 41-43.

Dunbar, Gary and Foster, Scot. (June 1996). "For Remediation Managers," *Civil Engineering*, Vol. 96 (6), p. 53-55.

Environmental Solutions Program (ESP). (April 1997). A Speaker at the Spring Research Review Meeting, Organized by Raymond C. Loehr, The University of Texas at Austin. Austin, TX.

Fairweather, V. (May 1996). "When Toxics Meet Metal," *Civil Engineering*, Vol. 96 (5), p. 44-48.

Fiedler, L. and Quander, J. (October 1996). "Over 300 Innovative Treatment Technologies Selected at Superfund Sites: New Database Provides Search Capability," *Environmental Manager*, Air & Waste Management Association, Pittsburgh, PA, p. 21-25.

Ginevan, M. E. and Splitstone, D. E. (February 1997). "Improving Remediation Decisions at Hazardous Waste Sites with Risk-based Geostatistical Analysis". *Environmental Science and Technology*, Vol. 31 (2), p. 92-96A.

Kenkeremath, Nandan. (September 1996). "Restoring Reason to Regulation: Applying Scientific Assessment and Cost-Benefit Analysis to Environmental Law," *American Industrial Hygiene Association Journal*, Vol. 57 (9), p. 791-793.

Koch, James E. (1994). A Risk Management Model for Environmental Remediation Projects. University of Missouri, Rolla, MO.

Kovalick, Walter W., Jr. (1995). "Technology Needs and Trends for Hazardous Waste Site Remediation," Proceedings of the National Conference on Innovative Technologies for Site Remediation and Hazardous Waste Management, July 1995, Pittsburgh, PA. American Society of Civil Engineers, p. 1-4.

LaGrega, M. D.; Buckingham, P. L.; and Evans, J. C. (1994). Hazardous Waste Management. Environmental Resources Management Group (ERM) and McGraw Hill, Inc., New York, NY.

Lifson, Melvin W. and Shaifer, Edward F. (1982). Decision and Risk Analysis for Construction Management. John Wiley and Sons, Inc., New York, NY.

Lindhult, Eric C. and Kwiecinski, Daniel A. (May 1996). "Cleaning Up Clay," *Civil Engineering*, Vol. 96 (5), p. 49-51.

Martin, K. and Oppenheim, J. (24 April 1995). "Environmental Management for the Petroleum Industry Enters a New Phase," *Engineering News Record*, Vol. 234 (16).

McConagle, J.; O'Ham, J.; Dagdigian, J.; Ngo, C.; and Wong, A. (1996). "Removal of Petroleum Hydrocarbons and Other Organic Compounds from Contaminated Soil with a Low Temperature Thermal Desorption System," Proceedings of the International Conference on Energy and Environment, May 1995, Shanghai, China. Begell House, Inc., New York, NY, p. 766-769.

Microsoft® Corporation. (1994). Microsoft® Access User's Guide.

Miller, Ross N.; Haas, Patrick; Faile, Marty; and Taffinder, Sam. (1995). "Risk-based Approach to Petroleum Hydrocarbon Remediation," Air Force Center for Environmental Excellence (AFCEE), Brooks Air Force Base, San Antonio, TX.

O'Melia, B. C. and Parson, D. R. (1996). "Dual-Phase Vacuum Extraction Technology for Soil and Ground-water Remediation: a Case Study," American Society for Testing and Materials (ASTM) Special Publication: Proceedings of the 1994 Symposium on Volatile Organic Compounds (VOCs) in the Environment, Montreal, Canada. ASTM, Conshohocken, PA, p. 272-286.

Raber, Linda. (18 November 1996). "Report Urges Congress to Adopt Unified Environmental Statute," *Chemical and Engineering News*, Vol. 74 (47), p. 7.

Rudin, M. J.; O'Brien, M. C.; Richardson, J. G.; Morrison, J. L.; and Morneau, R. A. (October 1993). "Performance-based Methodology for Rating Remediation Systems," *Journal of the Institute of Nuclear Materials Management*, Vol. 22 (1), p. 31-35.

Shanoff, Barry S. (October 1996). "Environmental Survey Supports State/Local Role," *World Wastes*, Vol. 39 (10), p. 18-20.

Scalf, M. R. (December 1992). "EPA's Superfund Technical Support Project," *Journal of Hazardous Materials*, Vol. 32 (2-3), p. 313-319.

Spain, Jim C. (August 1992). "Biotech Research: A Proactive Approach," The Military Engineer, Vol. 551, p. 52-55.

Tusa, Wayne K. (March 1992). "Reassessing the Risk Assessment," *Civil Engineering*, Vol. 92 (3), p. 46-48.

Wendel, Donald. (November 1995). "Contingency Estimating for Environmental Remediation Projects," *Cost Engineering*, Vol. 37 (11), p. 43-46.

Wilson, E. K. (3 July 1995). "Zero Valent Metals Provide Possible Solution to Groundwater Problems," *Chemical and Engineering News*, Vol. 73 (27), p. 19-23.

U. S. Army Corps of Engineers. (1995). United States Air Force Presumptive Remedy Engineering Evaluation/Cost Analysis (PREECA). Radian International, Austin, TX.

U. S. Environmental Protection Agency (EPA). Technology Innovation Office. (1997). Hazardous Waste Clean-up Information Web Site (http://clu-in.com). Internet.

U. S. Environmental Protection Agency (EPA). Technology Innovation Office. (April 1996). "A Citizen's Guide to Innovative Treatment Technologies," *EPA 542-F-96-001*. National Center for Environmental Publications and Information, Cincinnati OH.

Zuberi, Shakir. (1992). "Remediation Technologies for Environmental Restoration," Proceedings of the 1991 Portland International Conference on Management of Engineering and Technology. IEEE Engineering Management Society, Piscataway, NJ.

Vita

Scot Tolbert Allen [redacted] After completing high school at Governor Thomas Johnson High School in Frederick, Maryland in May 1983, he entered Carnegie Mellon University in Pittsburgh, Pennsylvania. In May 1988, following studies in Pittsburgh and a one-year exchange program at the École Polytechnique Fédérale de Lausanne, Switzerland, he graduated with a Bachelor of Science degree in Civil Engineering and French. Also in May 1988, he was commissioned into the United States Air Force as a Second Lieutenant. He served at Cannon Air Force Base, New Mexico; Ta'if Air Base, Kingdom of Saudi Arabia; Einsiedlerhof Air Station, Republic of Germany; and Istres Air Base, France in roles as a Civil Engineer and as a French interpreter. He married the former Yvonne Marie Bennett on 8 August 1992 in DuPaige County, Illinois. In August 1996, he entered The Graduate School at The University of Texas at Austin.

[redacted]

This thesis was typed by the author.

CIVILIAN INSTITUTION PROGRAMS (AFIT/CI)

FOR OFFICIAL USE ONLY

As Of: 4 September 1997

Col Copp
879-2172

Sally Tirone*
1-323-4412

SMSgt Charles
256-0764

TSgt Colasante
878-3568

SrA Banks
UNLISTED
258-3672

AB Douglas
754-0628

Maj Tolle
436-3731

Capt Ulman
866-2064

1Lt Wolff
253-9346

Lisa Freeland*
274-1125
Mary Ellen Ogle*
236-4701
Dick Gainor*
256-2290
Amy O-Liebold*
256-1804

Lt Col Keeling
837-5387

Maj Johnson
1-675-6381

Capt Wooten
667-8380

SSgt Ignasiak
252-4681

Stephanie France*
UNLISTED
252-0586

Carole Otten*
1-372-8700

Mary Neely*
435-0402

Janetta Long*
436-3832

NOTE: DO NOT RELEASE NUMBERS TO ANYONE

** Civilians - Call ONLY in case of inclement weather or emergency. Program Managers will notify their assistants.*

FOR OFFICIAL USE ONLY

RECALL PLAN

1. When notified, listen carefully to the information being transmitted. Then contact the next person in the chain, reading verbatim the recall message script and pertinent information you received. If you are unable to make contact, proceed to the next person in the chain. Do not break the chain. Try again at a later time to contact the person you were unable to notify. Do not include civilians in recalls. However, civilians will be notified of severe weather, base closures, etc.

2. For telephone notification test (i.e. Recall Message Script #2), the last person on the pyramid notification page will note the time the unit completes its recall, and will pass the time to the individual at the top of the roster. Upon final completion of the notification, the top person in the school/directorate pyramid will forward the time to AFIT/XO, #55760

AFIT RECALL MESSAGE SCRIPTS

MESSAGE 1 - INFORMATION. This format is used to pass any kind of operational or base information when speed of dissemination is important. Do not report for duty.

TEXT: "This is _________ with AFIT Pyramid Alert Message 1. Copy the following information:_________. Acknowledge receipt and pass it on."

MESSAGE 2 - NOTIFICATION TEST. This format permits the periodic exercise of the Pyramid Alerting System to detect breaks in calling line continuity and demonstrate overall system viability. Do not report for duty.

TEXT: "This is _________ with AFIT Pyramid Alert Message 2. Acknowledge receipt and pass it on."

MESSAGE 3 - Not Used.

MESSAGE 4 - RECALL. This format is used to call all AFIT personnel to duty. All AFIT personnel report to duty sections immediately. Recall time MUST BE PASSED as part of the message.

TEXT: "This is _________ with AFIT Pyramid Alert Message 4. Recall time is _________. Acknowledge receipt and pass it on."

MESSAGE 5 - Not Used.

PRIVACY ACT STATEMENT

AUTHORITY: 10 USC 8012

PRINCIPAL USE. This information (name and phone number) is required for the rapid notification and/or recall of AFIT personnel during nonduty hours. This may be required because of emergencies on base, exercises, or general war/mobilization. It can also be used to pass other vital information to unit members during nonduty hours.

ROUTINE USES: The information may be used by unit personnel as a ready reference for contacting other unit personnel at home for official purposes.

DISCLOSURE: (MANDATORY) Failure to provide this information could jeopardize the operation of the base and AFIT.

CIVILIAN INSTITUTION DIRECTORY LISTING AS OF: 04 September 1997

PHONES: TOL FREE 1-800-543 3490/3577/3578 COMMERCIAL: 513-255 + NBR DSN: 785 + NBR EMAIL: username@afit.af.mil

FAX NBR: DSN 785-5371 COMMERCIAL:513-255-5371

OFFICE / DUTY TITLE	PROGRAMS	NAME	E-Mail	PHONE	EXT
CI	**DEAN CIVILIAN INSTITUTIONS**				
DEAN		COL PAUL D COPP	pcopp	52259	2002
ASSOCIATE DEAN/CH HEALTH CARE EDUCATION		LT COL CLAUDE E KEELING	ckeeling	52023	2007
SUPERINTENDENT		SMSGT MARK D CHARLES	mcharles	52259	2003
SECRETARY TO THE DEAN		MS SALLY F TIRONE	stirone	52259	2001
CIA	**ADMINISTRATION**				
FINANCIAL MANAGER		TSGT PETER J COLASANTE	pcolasan	52259	2007
ADMINISTRATIVE SPECIALIST		SRA CAROL S BANKS	cbanks	52259	2005
BUDGET ANALYST		MRS JAY NEWLAND	jnewland	52259	2008
INFORMATION MANAGEMENT APPRENTICE		AB DESMOND D DOUGLAS	ddouglas	52259	2006
CIG	**GRADUATE EDUCATION DIVISION**				
ASSISTANT PROGRAM MANAGER		MRS MALISA FREELAND	mfreelan	53151	2012
ASSISTANT PROGRAM MANAGER		MRS MARY ELLEN OGLE	mogle	53291	2021
CIGC	**PCE (LINE OFFICER)/BOOTSTRAP**				
PROGRAM MANAGER		MR RICHARD P GAINOR	rgainor	53151	2019
CIGD	**CIVIL ENGINEERING/LEGAL/CHAPLAIN PROGRAMS**				
PROGRAM MANAGER		1ST LT GREGORY C WOLFF	gwolff	53293	2024
CIGH	**EDUCATION WITH INDUSTRY**				
ASSISTANT PROGRAM MANAGER		MS AMY R O'BRIEN-LEIBOLD	aobrienl	53151	2015
CIGS	**ACADEMY FACULTY PREP**				
PROGRAM MANAGER		MAJ RALPH C TOLLE	rtolle	53291	2013
CIGW	**METEOROLOGY/AFIT FACULTY PREP**				
PROGRAM MANAGER		CAPT JAMES C ULMAN	julman	53291	2022
CIM	**HEALTH CARE EDUCATION DIVISION**				
CHIEF, HEALTH CARE EDUCATION		LT COL CLAUDE E KEELING	ckeeling	52023	2027
ASSISTANT PROGRAM MANAGER		MS STEPHANIE A FRANCE	sfrance	52023	2028
CIME	**PCE (MEDICAL PROGRAM)**				
PROGRAM MANAGER		SSGT GLEN S IGNASIAK	gignasia	55825	2031
CIMI	**ALLIED HEALTH EDUCATION PROGRAMS**				
PROGRAM MANAGER		MAJ JOHN J JOHNSON	jjohnso	55826	2029
ASSISTANT PROGRAM MANAGER		MRS CAROLE K OTTEN	cotten	55826	2033
CIMJ	**HEALTH PROFESSIONS SCHOLARSHIP PROGRAM**				
ASSISTANT PROGRAM MANAGER		MRS JANETTA M LONG	jlong	55824	2034
PROGRAM MANAGER		CAPT JAMES O WOOTEN	jwooten	55824	2036
ASSISTANT PROGRAM MANAGER		MRS MARY C NEELY	mneely	55824	2035